INVESTIGATION OF THE QUALITY OF EDIBLE OIL (NIGER) BY LASER LIGHT SCATTERING TECHNIQUE

By: Fantahun Geta Shume

A Thesis Submitted to

The Department of Applied Physics

School of Applied Natural Science, ASTU

In Partial Fulfillment of the Requirements for the Degree of Master in Physics

August28, 2018

Adama, Ethiopia

INVESTIGATION OF QUALITY OF EDIBLE OIL (NIGER) BY LASER LIGHT SCATTERING

By: Fantahun Geta Shume

Advisor:Alemu Kebede (PhD)

A Thesis Submitted to

The Department of Applied Physics

School of Applied Natural Science

Presented in partial fulfillment of the requirements for the degree of master in

Physics

Office of Graduate Studies

Adama science and Technology University

August, 2018

Adama, Ethiopia

DECLARATION OF THE AUTHER

I hereby declare that this MSc. Thesis Dissertation is my original work and has not been presented for a degree in any other Universities, and that all the sources of materials used for this thesis dissertation have been dully acknowledged.

Name: Fantahun Geta

Signature: ___________________

Place and time of submission: Adama Science and Technology University, August, 2018

This M.Sc. thesis dissertation had been submitted for examination with my approval as thesis advisor.

Name: Alemu Kebede (PhD)

Signature: ______________________

August, 2018

Adama, Ethiopia

APPROVAL SHEET

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF APPLIED NATURAL SCIENCE

APPLIED PHYSICS PROGRAM

This is to certify that the thesis prepared by Fantahun Geta in titled **”Investigation of quality of edible oil by laser light scattering technique**” Submitted in partial fulfillment of the requirement for master degree of science in physics complies with the regulation of the university and meets the accepted standards with respect to originality.

Signed by the examination committee

Name	Signature	Date
___________________________	______________	________________
Advisor		
___________________________	______________	________________
Chairman		
___________________________	______________	________________
External Examiner		
___________________________	______________	________________
Internal Examiner		

August, 2018

Adama, Ethiopia

Table of Contents

List of Figures

List of Tables

List of Acronyms

HPLC -High performance liquid Chromatography

FFA -Free fatty acid

POV- Peroxide value

BC-Before Christ Birth

d_{50}= smallest sieve opening through which 50% of the material passes.

EMR- Electromagnetic radiation

AM/FM radio waves

LASER- Light Amplification by Stimulated Emission of Radiation

EM wave- Electromagnetic wave

RTE - Radiative Transfer Equation

List of symbols

- mm- millimeter
- cm-centimeter
- μ -micron
- μ_a _absorption coefficient
- $\mu_s^{/}$ -reduced scattering coefficient
- μ_s -scattering coefficient
- g -anisotropy factor
- Q_S -scattering efficiency
- L_t -optical path length
- μ_t -total attenuation coefficient
- μ_{eff} -effective attenuation coefficient
- D -diffusion coefficient
- $\varepsilon_a - absorption\ extinction\ coefficent$ _
- α -the optical albedo
- σ_a -absorption cross section
- ρ_s -density of scattering particle
- ρ - The number density of molecules
- I_O -initial intensity
- I -final intensity
- R -reflectance
- d -diameter of particle
- r -radius of particle
- λ -wave length
- θ -angle

- θ_i -incident angle
- θ_t -transmitted angle
- n_1 -refractive index for external medium (hexane)
- n_2 -refractive index of the medium (edible oil)
- m -the refractive index of the scattering particle
- m_o -the refractive index of the medium
- λ_o -the incident wave length in vacuum
- n -relative refractive index
- x -size of particle
- c -speed of light in the vacuum
- v -speed of light in material
- σ_s -scattering cross section
- A - Geometrical area of particle

ACKNOWLEDGEMENTS

First of all, I would like to thank the Almighty God who made everything in this world possible, and he who helped me to begin and finish this work successfully as it is expected. I do not have adequate word to express my feelings of gratitude to my advisor Dr. Alemu Kebede whose benevolent guidance and constant encouragement helped me to complete the present research work successfully. He is the person who has always helped me. His constant encouragement made me strong enough to face every ups and down with confidence during this research study.

I would like to acknowledge Mr.Tesfaye Mamo, assistant of advanced optics lab at Addis Ababa University who helped me by expending times with me during the experiment. His technical assistance when I was working the experiment gives me guidance for the analysis too.

Words cannot express my feelings which I have to my wife Fikre Wakjira, my brather Zemachu Geta, my son Miressa Bekabil, and the whole family. I am highly indebted to them for their blessing, guidance, advice, encouragement and support me in all direction.

I would like to give my special thanks to my friends, Shiferaw Gurmu, Guluma Nagaro and many others for their constant encouragement, editing this research paper and help which give me enough strength to carry out the present research and for the whole friendship.

ABSTRACT

The main technique of this work is to investigate the quality of edible oil by using laser light scattering. In this experiment a continuous wave frequency 35 mw He-Ne (632.8 nm) laser, lock-in amplifier, chopper, spectrometer scale was used as an apparatus. Niger oil was used as sample. The experimental set up was carried out and necessary data were recorded, and then analyzed to get different optical properties and particle size of edible oil sample. The optical properties of the diffusing medium (Niger oil) such as the absorption, scattering, reduced scattering, effective attenuation coefficients and anisotropy factor were determined and tried to relate with the quality of edible oil. In this research, efficient and objective discrimination of edible oil varieties and quality determination method is developed by investigating particle size dependency of quality of edible oil by using laser light scattering technique. Particle size determination for Niger oil was performed after determination of its optical properties with three phases of experiments. The results show that, the tested sample has high scattering coefficient in the forward direction as compared to its negligible absorption coefficient and its scattering coefficient has direct relation with its particle size as well as its quality, the larger the scattering coefficient is the finest the particle size and the highest the quality. In general the obtained results were in good agreement with Mie scattering theory in the review literature. Thus, the developed method has wider economic and scientific applications, even for other turbid mediums. Light scattering method is recommended as alternative method for classification of edible oil quality standards.

1. INTRODUCTION

1.1. Background of the study

Niger and sesame are major oil seeds crops grown in Ethiopia [1]. Oil seeds are leading suppliers of superior quality and specialty vegetable oils nutritional products, natural food and premium snack foods worldwide [2]. Oilseeds are rich sources of nutrients and also have wide range of medicinal values. They add important nutritional values to diets as they are sources of vegetable oil, high quality properties as well as oil soluble vitamin A. Though there are oil bearing tree fruits which come first in terms of oil content, oilseeds are the largest source vegetable oils [3]. Oilseeds are primarily used for the extraction of edible oils. The defatted meal is a rich source of protein and, if suitable processed has great potential as food for human consumption. Some oilseeds are consumed as such and, though in small amounts, contribute to the daily intake of several nutrients [4]. Edible oils are in common use in the home as butter, margin, dripping and vegetables. Edible oils are characterized by a wide range of physical and chemical properties; since their composition depends on the type of oil. Oil suitability for most uses depends on its quality and chemical composition. Several tests can be used to determine oil purity, such as the determination of triacylglycerols, Ts, sterols and other constituents of unsaponifiable fraction of oil [5].

Quality is a degree of excellence in which something distinguishably attributed. It may depend on different factors in which how and what measurements of an object (matter) take place. Different parameters can affect the quality of edible oil. External and internal factors can contribute to the quality of edible oils. Mainly man and nature are external factors. Natural phenomenon include altitude, duration and severity of rainfall, type of soil, pH, genetic origin, location of producing area, chemicals, and pesticides, harvesting methods and timing, packing and so, forth [6]. Vegetable oils such as safflower, olive, corn, soy, and canola have been employed for a variety of purposes, including: additives for cosmetics, soaps, health supplements, and foodstuffs; as well as disease prevention. The source and nature of the oil is relevant, as harmful oil impurities can have a significant impact on health and wellbeing. This application note describes the analysis of several edible oils that employ state of the art technology, including waters [9]. High performance liquid Chromatography (HPLC) and gas chromatographic methods comprise most analysis techniques done today on edible oils. Other techniques-including supercritical fluid chromatography, mass spectrometry, nuclear magnetic resonance spectrometry, and many other techniques have also been employed and thoroughly reviewed [7].

Edible oil variety identification is very useful in encouraging good quality oil production ensuring dependable and competent exporters as well as creating lasting business relationship with overseas clients. In Ethiopia, the method of edible oil variety identification is through traditional inspection and previous experiences which is subjective non efficient. The basis of edible oil variety identification is often subjective with attributes color, size, thickness frequently examined by human inspectors. It also found that human perception could easily be biased. As a result, objective discrimination of edible oil varieties and quality determination is necessary which is consistent, non-destructive and cost effective for commercial purposes. In light of these, it is useful to explore the possibilities of adopting the most economical and faster system which saves time and is more accurate in classification of quality of edible oil by reducing observer effects of biases pertaining to the quality standard that enhances the commercial needs. One of such best methods is scattering of laser light using edible oil.

For many years measurement techniques based on laser light scattering theory have been applied to obtain information about the size, structure, shape, composition and concentration of substances. Scattering experiment is an applied spectroscopic technique that used to study the physical system when it interacts with electromagnetic radiation. Moreover it is spectroscopic technique that studies about the production, transmission and detection of light with relation to the optical properties of a material medium [8]. In this work the we use laser light scattering experiment to investigate the particle size dependency of edible oil quality.

1.2. Statement of the Problem

Oil and fat are important constituents of our diet and contribute significantly for development and regulation of different functions of our body. The main sources of oil and fat are plants, marine and animal sources. These are necessary for a healthy life and one third of total calories must come from oil and fat. Major edible oil is extracted from soybean, sunflower, cottonseed, canola, Niger seed and olive. Quality of edible oil can be judged by testing different parameter of cooking oil. Free fatty acid (FFA), Peroxide value (POV), Colors values indicate and give information quality of raw material, processing, storage conditions, degree of purity and quality of bleaching. Different studies were conducted to evaluate the quality of edible oil. The physiochemical qualities of oil brands were investigated for free fatty acid, peroxide value, smell, weight, color, foreign matter, appearance and cold points [8, 9].

In Ethiopia, different researchers did the research to test the quality of edible oil by Sensor, physiochemical, analytical method in terms of acid value, peroxide value, saponifiable and biofuel potential and by the method of traditional inspection and previous experiences in terms of color, size, thickness, odor which is subjective non efficient and frequently examined by human inspectors [9, 10]. However, to our knowledge no study has applied laser light scattering technique to test the quality of edible oil. Therefore, the main interest in this study was to explore the possibilities of adopting and use of alternative, economical and faster system that would save time and more accurate in classification of quality of edible oil. To this end, the study uses laser light scattering experiment to investigate the particle size and optical property dependency of edible oil quality.

1.3. Objectives of the Study

1.3.1. General Objective of the Study

The main objective of this thesis is to investigate the dependency of quality of edible oil on particle size using laser light scattering experiment technique.

1.3.2. Specific Objectives of the Study

The specific objectives of the research are

- To determine the optical properties of the sample absorption, scattering, and extinction coefficient and anisotropic factor for edible oil.
- To measure the intensity of the transmitted light through the sample-to determines the scattering particles size by angular distribution of intensity measurement.

1.4. Scope of the Study

This study is limited to checking the quality of edible oil (Niger) only depending on the optical properties and particle size but does not include other type of oils.

1.5. Limitation of the Study

Due to lack of time and budget the study is limited to optical property analyses of edible oil and does not include other methods, the impurities may found in the sample oil since it was bought from local market.

1.6. Significance of the Study

The main importance of doing this work on the laser light scattering for investigation of quality of edible oil (Niger) is that:

- To create awareness that the role of laser light scattering to test the quality of oil depending on their optical property.

1.7. Beneficiaries of this Research

- It helps producers and traders to use the method as an alternative method to check oil quality.
- The results obtained from this research can be used as an input by other researcher.

1.8. Application of the Results

This Research concerns about the laser light scattering for investigation of particle size dependency of quality of edible oil under controlled conditions have many applications.

The applications area of this research is:-

- In the quality inspection center
- In the food processing industries

1.9. Organization of the Thesis

Chapter 1: Introduction, back ground, objective, significance, beneficiaries and application of the study presented. Chapter 2: review of related literatures in which the historical, purpose and extraction of Niger oil as well as theory of electromagnetic magnetic radiation, laser light property and its application, light propagation theories, model of light propagation through isotropic dielectric material medium is presented. Chapter 3: Different methods and materials used in this study are presented, Chapter 4: Results and discussion are presented, Chapter 5: Conclusion and recommendation for future works of the research are presented. Finally, Reference materials used in this research are presented as bibliography.

2. REVIEW OF RELATED LITERATURE

2.1. The plant

Niger is an annual dicotyledonous herb. With epigeal germination the root system is well developed with a central tap-root and its lateral branching. The stem of Niger is usually round, smooth to slightly rough, hollow and moderately branched. The fruit is an achene, small, 3-5 mm in length and 1.5 mm in width, almost lanceolate in shape, without pappus. There are usually between15 and 30 mature seeds /heads; occasionally more and varying number of immature seeds is pops at the center [11, 15].

2.2. Origin and History

The evidence suggests that Niger originated in the high lands of Ethiopia, north of 10^{o} latitude. Cultivated Niger might have originated from the wild species Guizotia scarab subsp.schimperi due to selection by Ethiopian farmers thousands of years ago. The genus Guizotia has 6 species. All species except G. abyssinica are wild and more endemic to East Africa especially Ethiopia. From Ethiopia the cultivated Niger is believed to have spread to India during third millennium BC along with other crops, such as finger millet. Niger's wide dispersal in India is indicated by the great Varity of local names for the plant and seed [11, 13].

2.3. Niger oil

The Botanical name of Niger is Guizotia abyssinica and it is from the Family of Asteracae (compositae). Niger is a minor oilseed crop which is important under rain fed conditions, coarse textured and poor soils, especially on hill slopes. Niger seed is used as a human food. The seed contains 37-47% oil, which is pale yellow with nutty taste and a pleasant odor. The oil and seeds are free from any toxin. The oil is readily subject to oxidative rancidation rendering its keeping quality poor due to high content of unsaturated fatty acid (oleic acid 38% and linoleic acid 51.6%). The oil is used for culinary purposes, anointing the body, manufacturing paints and soft soaps and for lighting and lubrication. The Niger oil is good absorbent of fragrance of flowers due to which it is used as base oil by perfume industry. Niger oil can be used for birth control and treatment of syphilis [11]. Niger sprouts mixed with garlic and 'tej' are used to treat coughs. Niger seed cake is a valuable cattle feed particularly for milk cattle. Niger meal with 30% protein and 17% crude fiber in India could replace linseed cake in calf ration. It can also be used as manure. Niger is also used as a green manure for increasing soil organic carbon [11].

2.4. Developments in Oil Expression/Extraction

Oil extraction from both animal and plant origin had been known since ancient time. Manual crushing of the seeds using simple available tools, rendering, pressing manually or powered by animals and filtering are among the old methods some of which can still be traced in some parts of the World. Today using high technology seed treatment, pressing, refining, and where necessary modifying the oil by secondary processing, packaging is possible. The current technology has reached high precision taking into account almost all minor but important components in the oil [16].

2.4.1. Historical Aspect of Oil Extraction Techniques

Documented oil extraction dates back to 1650 B.C. when ripened olives were pressed by hand in Egypt using wooden pestles and stone mortars. The extracted olive oil was filtered through goat hair filters and used as a lubricant. Sesame, linseed, and castor oils were recovered in Egypt by hand pressing as far back as 259 B.C. By 184 B.C., the Romans developed more sophisticated technology such as edge runner mills and screw and wedge presses. These technologies combined leverage and the use of animal power to aid in the milling and extraction of the oil. From Roman times until the eighteenth century, similar technology was used for oil extraction [16, 17].

a. Hydraulic Press

In 1795, J. Bramah of England invented the hydraulic press for oil extraction. For this press oilseeds were milled, cooked, and wrapped in filters cloths woven from horse-hair. The oilseeds wrapped in filter cloths were manually loaded into perforated, horizontal boxes below the head block and above the ram of the press. The boxes were pressed together using upward hydraulic pressure on the ram. The oil was pressed out through the filter cloths surrounding the oilseeds. The filter cloths and spent cake were manually removed from the hydraulic press. The residual oil in spent cake was approximately 10%. Since its discovery various modifications and advancements had been made to hydraulic press from its simplest form to the most advance one. Today, hydraulic press is used only for olive oil and cacao butter pressing.

In 1900, Alfred French founded the French Oil Mill Machinery Company in Piqua, Ohio, for the purpose of advancing hydraulic press technology. He was awarded a patent for the automatic cake-trimming machine for automating the sizing of the cakes prior to pressing. He also developed and patented the ‘‘change valve’’ in1905, which allowed the hydraulic press to change pressures near the end of the pressing cycle to squeeze additional oil. The continuous stacked cooker was patented in 1907 along with an innovative cake former. Two pass pressing was another of French's developments, taking final residual oil in cake below 5%. Depending on the type of material, subsequent process, intended use, quality desired, and efficiency there can be different mechanisms of oil expression from plants (seeds, nuts, fruits…). Around 1890, oilseeds were pressed in manually loaded batch presses. Oilseed wrapped in filter cloths, separated by stacked layers of plates in hollow perforated cylinder and applied pressure through a manually operated jack screw or a hydraulic cylinder. Oil flows from the compressed material into the hollow plates and then oozes through the perforated side wall of the cylinder. Manually operated jack screw has been used for hundreds of years. With the advent of hydraulic cylinders the presses became more efficient and less labor intensive and also more oil is liberated due to high pressure. In the early 1900s hydraulic presses dominated the oilseed crushing industry. The hydraulic press itself was considered to be labor intensive when continuous screw press was developed. Today, the continuous screw press is the dominant one in mechanical press. The only application still favoring hydraulic press is cocoa butter from cocoa beans where the defatted residue is to be fine-ground into cocoa powder and olive oil Competition was between limited numbers of companies in the world [18].

b. Screw Press Extraction

Valerius D. Anderson (Anderson International Corp., Cleveland, Ohio) developed continuous screw press in 1900. He used a continuous press design in 1876 and tested a serious of screw-conveyer like devices that had perforated walls and a flapper-type choke at the discharge end. He later on made a breakthrough discovery providing interruptions to the screw flight i.e. mounted on a central shaft so as to have some unlighted space between the segments. This solved the problem of the product spinning with the shaft every time the choke is closed. The shaft is placed in a cylindrical housing with holes drilled throughout to allow oil to escape upon pressing [19].

c. Solvent Extraction

Solvent extraction is a process in which a solvent (such as hexane) is used to separate the oil from the oil-bearing materials. It is a demanding process, using highly inflammable chemicals, and it is only practiced at a relatively more sophisticated industrial scale. The advantage of solvent extraction is the high efficiency of extraction that can be obtained economically with this method (>99 wt. %). But can be at the expense of reduced oil quality resulting from residual solvent chemicals if the technology is not high level. The advantage of solvent extraction is the high yield/efficiency but this demands high initial investment and skilled technician. Therefore it is less recommended where the technology is not well refined and the skill is not reliable [20].

2.4.2. Compressive Pressure by Screw Press

A screw press is a mechanical device that accepts a continuous stream of fat bearing material, compresses it under very high pressure to squeeze out the fat, and then discharge a continuous stream of squeezed solids. The function of a screw press is to separate liquids including oil from solids by expelling the liquids through a screen that surrounds the compression screw. It applies pressure to make the fluid flow through the holes or slots in the screen. As screw presses evolved, a number of mechanisms have been found useful for this separation process as follows.

Firstly the compression can be achieved by gradually increasing the shaft diameter of the screw. This forces the material out against the screen so that liquid is expelled through the screen as the clearance between the wall and the shaft progressively decreases along the length towards the discharge Secondly, compression can be achieved by tightening the pitch of the fighting. As the number of the screw turns per unit length decreases towards the discharge there is more material being forced into the press than is being removed. This results in increase in pressure with decrease of pitch. A third way to achieve compression is to install a cone at the discharge. This cone is also referred to as a choke, stopper or door. In many screw press designs cone is bolted into a fixed position, creating a fixed discharge orifice or changeable cone with varying orifice diameter [6].

2.5. Size and Properties of Particle

Particle size can affect "processability" (larger particle flow slowly and smaller particle at faster rate that is in flow, mixing, compaction …) and final formulation, that is, performance, appearance, and stability of particles. Nearly all, industries and research fields that handle is materials need or demand to analyses particle size and/or shape. The flow characteristics of solid particles in a gas–solid suspension vary significantly with the geometric and material properties of the particle. The geometric properties of particle include their size, size distribution, and shape. Particles in a gas- solid flow of practical interest are usually of non-spherical or irregular shape and poly dispersed sizes. The geometric properties of particles affect the particle flow behavior through an interaction with the gas medium as exhibited by the drag force, the distribution of the boundary layer on the particle surface, and the generation and dissipation of wake vortices. The material properties of particles include such characteristics as physical adsorption, elastic and plastic deformation, ductile and brittle fracturing, solid electrification magnetization, heat conduction and thermal radiation and optical transmission. The material properties affect the long and short-range inter-particle forces, and particle attrition and erosion behavior in gas-solid flows .The geometric and material properties of particles also represents the basic parameters affecting the flow regimes in gas-solid systems such as fluidized beds [21].

2.6. Particle Size and Sizing Methods

The methods for determining particle size are; Microscopy $(1\mu m - 1\,mm)$), Sieving, Sedimentation techniques($>1\mu m$), Optical and electrical sensing zone method, Laser light scattering techniques(particle size range $0.02 - 2000\mu m / 0.01 - 3500\mu m$).The number of technique employed for particle size determination exemplifies its importance microscopy methods, light interaction methods, Electrical property methods, Sedimentation methods , sorting and Classification methods and perhaps, indicates the difficulty in acquiring this information. Of the five methods techniques listed above ,this research addresses only the light interaction method and laser light scattering technique within that energy category. To fully describe light scattering phenomenon, familiarity with several supporting theories is required. That background is provided here, but only to the extent necessary to provide continuity in the discussions that flow. Detailed information is available from various sources and the reader will need to research those sources if technical details are desired. This study focuses only on the details pertinent to the main subject which is particle size dependency of quality of edible oil by de-convolution of the light scattering using Mie theory [21, 42].

2.7. Particle Size Analysis

Among the particle size analysis, Sieve analysis is performed using a nest or stack of sieves where each lower sieve has a smaller aperture size than that of the size above it. Traditionally the size of particle has been measured using Sieved-based methods. The method classifies particle size as in the table 2.1.below.

d_{50}= smallest sieve opening through which 50% of the material passes.

Table 2. 1: Classification of the size of particles.

classification of particles	**d_{50} –sieve opening (μm)**
very coarse	>1000
Coarse	355-1000
moderately fine	180-355
Fine	125-180
very fine	90-125

Although sieving has provided as a means of differentiating between different grinds, it is both laborious and does not provide an accurate assessment of the amount of fine particles produced during milling. This lack ability to resolve changes in the fine fraction limits the capacity of the technique to help control the quality of the final product. Given the limitation of sieving, laser scattering /diffraction has become widely accepted for the characterization of edible oil. The measurements are also rapid, providing full size distributions in a few seconds. The technique is therefore suited to the requirements of production and quality control [22].

2.8. The Nature of Light

Energy transmitted by waves through a medium is called radiation or radiant energy; it includes electromagnetic sound and elastic waves. Electromagnetic energy includes cosmic rays,

$\gamma - rays$, x-rays, light, heat, microwaves, and radio waves. This continuum of energy is called the electromagnetic spectrum. Energy residing in a specific and very narrow band of this spectrum is referred to as 'light'. Wave theory often is used to describe electromagnetic radiation and therefore to describe light. Light waves, sound waves, water waves, etc. share some characteristics and can be studied using the same theories, but only in limited case. Although similar in some respects, there are considerably more differences than similarities between sound waves and electromagnetic waves. The same holds true when studying details of electromagnetic waves in different bands of the spectrum; theories that apply to one band of wave lengths may not apply well to another band. This document is concern only with light. Even within this narrow band of electromagnetic radiation interaction between light and matter may produce very different effects depending on the wave length of light or the characteristic of the material; these variable may be referred to as the condition under which an interaction take place. Interaction that results in what is called light scattering are no exception. So, any description of light scattering must be accompanied by qualifying statements that define the condition under which the statements (theories, explanation, or conclusions) are believed that to be factual. The discussions that follow hold fast to this caveat; terms are defined and statements are qualified as they pertain to the theoretical discussion. These definition and qualifications may be referred to as limitation, conditions, constraints, or boundary conditions. Regardless, they are what ultimately will separate the theoretical ideal from real-world applications of light scattering theory.

A few additional facts about light should be mentioned. The smallest bundle in which electromagnetic energy is packed is called a photon. All photons of light of a specific wave length have a specific quantity of energy. The intensity of light of a specific wave length is a function of the total number of photons emitted (or collected per unit area) per unit time. The study of optics also deals with light beams and light waves. A ray is an imaginary line that corresponds to the direction in which radiant energy flows. A light beam can be thought of as a group of parallel rays and having finite thickness; a light beam also may be considered as a stream of photons all moving in the same direction. To express it in another way a light ray is the limit of narrowness of a light beam. The branch of optics that is concerned with the path of light rays through optical system is called geometrical optics. Light and in fact, all electromagnetic radiation has a dual personality. Sometimes it behaves like a particle and sometimes it behaves like a wave, the wave most often being depicted as sinusoidal. This is the particle-wave duality characteristics often attributed to photons. In this document, light will be treated either as a continuous wave or as a photon, depending on which view best serves the current technical discussion [21, 22].

2.9. Theory of Light Propagation in an Isotropic Dielectric Medium

Propagation of light through material medium is the most important and interesting aspect of light. In this chapter the theories of interactions of light with matter will be discussed. Starting from the definition and properties of electromagnetic radiation this chapter presents how and what phenomenon take place when light and matter interacts. Moreover it deals about mathematical representations that can often be used for qualitative expressions of varied optical phenomenon exhibited by medium like reflection, absorption and scattering of light.

2.10. Electromagnetic Radiation

Electromagnetic radiation (EMR) is radiant energy that travels outward in all directions from its source through space with and without the need of material medium. There are different types of EMR, some very similar, and others rarely mentioned outside scientific discussions. Electromagnetic radiation includes AM/FM radio waves, microwaves, visible light, Ultraviolet radiation, X-rays, and gamma rays. Light is a form of electromagnetic radiation in the visible range from its broadened spectrum [9].

Electromagnetic radiation types are identified based on their frequency, wave length and sources. The energy sources that produce EMR vary greatly, from nuclear reaction in the sun, which generate gamma radiation, chemical reaction in the human body that generates infrared radiation (heat) [23]. The electromagnetic spectrum is the applied to all the types of EMR considered together in terms of frequency, wave length, or energy. All parts of the spectrum are found, with varying intensity, in our natural environment. We are most familiar with the visible spectrum since we sense it directly with our eyes and it rangesfrom 390 nm to780 nm wavelength.

The infrared spectrum in which its wave length λ >780 nm is sensed as heat and the ultraviolet spectrum (λ<390 nm) include radiation that can damage living cells, often causing a physiological response such as sun burn. Other parts of spectrum may present as background radiation. Natural background radiation originates from two primary sources: cosmic radiation and terrestrial sources. Cosmic radiation from deep space interacts with atoms in the atmosphere producing X-rays and unstable isotopes. Terrestrial sources of gamma radiation include radioactive isotopes of uranium, potassium and carbon [23]. The relative energy of the different types of EMR varies with frequency across the spectrum. The figure 2.1 below shows the distribution of electromagnetic radiation spectrum.

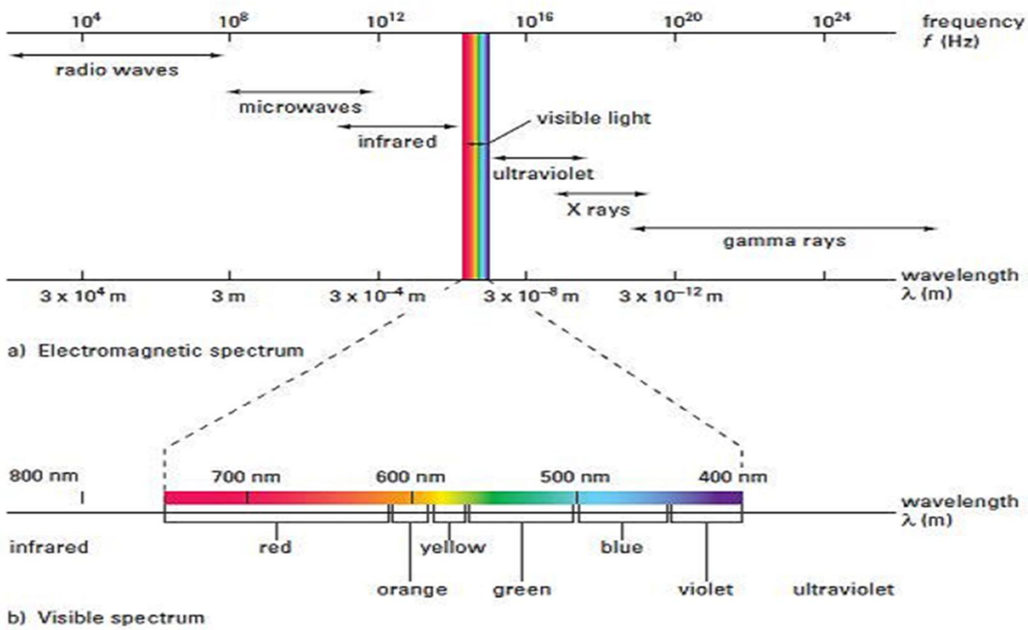

Figure 2. 1 : The electromagnetic spectrum showing the visible range [21, 22]

2.11. Laser and Laser Application

Most spectroscopic measurement techniques use a special light which has special properties for special conditions. The most known special light is laser light. The word LASER is an acronym for the most significant feature of laser action. Light Amplification by Stimulated Emission of Radiation. There are many different kinds of laser, but they all share a crucial element: Each contains material capable of amplifying radiation. Thus laser is a device that produces a beam of intense, directional (linearly polarized) and monochromatic light in which all the waves are in phase or are coherent. Laser has three basic components: laser active medium, energy source (or pumping system), and resonant optical cavity with reflecting mirrors. Active medium contains atoms or molecules whose electron may be excited to an elevated energy level by an external energy source to form population inversion. The excitation mechanism functions by pumping energy into the active medium by one or more basic methods that reflects essentially 100 % of light, and a mirror that allows partial transmission [23].

Many scientific, military, medical and commercial laser applications have been developed since the invention of laser in 1958. The coherency, high mono-chromaticity, ability to reach extremely high powers with narrow band width, large frequency tuning range over considerable values and all other properties of laser light allows it to play tremendous specialized application. The numerous fields of laser applications may be broadly categorized in to two groups.

One group involves applications where laser beam play a role of high power beam. This is exploited to produce a targeted effect on material. These applications include material processing. Example Welding, heat treatment, cutting, hole burning, isotopes separation etc. The other group includes data transmission and processing, measurements and quality control application [24].

The high purity/mono-chromaticity of laser makes it as a very useful source for spectroscopy. For many years measurement techniques based on laser light scattering theory have been applied to obtain information about the size, structure, shape, composition and concentration of substances. Thus, for this scattering experiment, a linearly polarized continuous He-Ne laser with 35 mw powers at 632.8 nm wavelengths is used to investigate scattering properties and particle size dependency of quality of edible oil.

2.12. Light Matter Interaction

When a beam of light is incident on material medium and propagates through it, various light-matter interaction phenomenons takes place. This interaction can occur at the surface or inside the medium components and the rest of light may penetrate the medium (transmission). Due to this interaction of light with the medium components there might be reflection on the surface and attenuation due to scattering and absorption in the medium by internal suspended components. The absorption properties are strongly dependent on the wave length of the incident light while reflection and scattering have negligible effect on the wave length of incident light. All these processes give concrete information about the size, concentration, motion and shape of the constituent of the medium. The information we will obtain from this experimental work has a paramount importance in calculating the optical properties of the medium and its particle size effects on the quality [25, 26].

The interaction of light with material medium depends on the composition, concentration of the medium, wavelength and energy of the light. A solution of edible oil is turbid and the molecule the edible oil in the solution may scatter most of light energy in all direction and it may have a little absorption peak on the corresponding wavelength. In any conditions of material medium, when light tries to propagate through the given medium, the properties of light that can be happen are; Reflection and refraction, Absorption and Scattering.

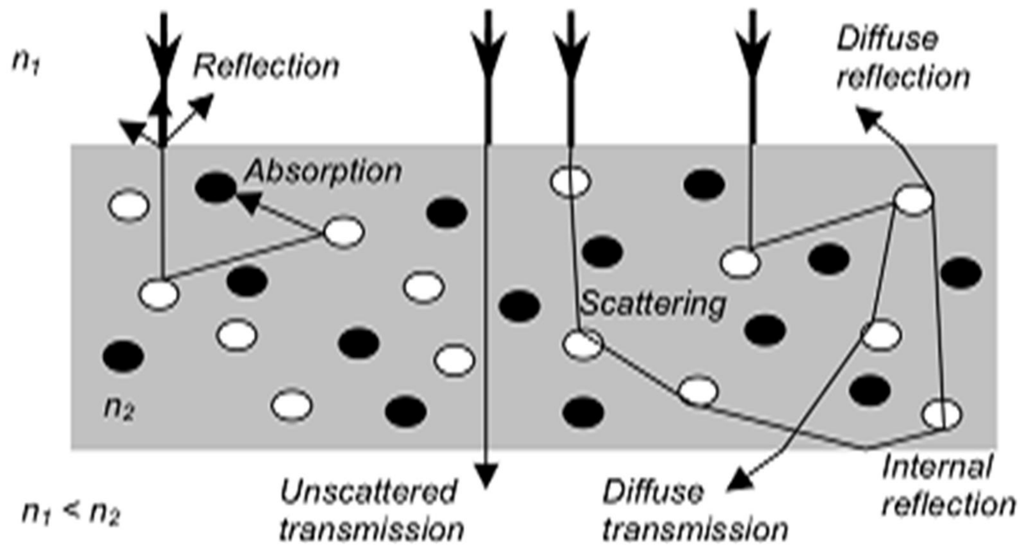

Figure 2. 2 : Geometry of Reflection, Absorption and Scattering [22]

2.12.1. Reflection and Refraction

Reflection and refraction are the most common phenomenon when light and matter interacts with each other. Light intensity will be reflected and/or refracted because of a refractive index mismatch between the air and the sample boundary. The intensity of both reflected and refracted light doesn't only depend on the difference in refractive index mismatch, but also depend on polarization, angle of incidence, wave length of light and structure and shape of the surface.

Reflection and refraction are strongly related to each other by Fresnel's law. Reflectance or the fraction of reflected intensity R, for unpolarized light is defined as the ratio of the reflected intensity from the medium to the incident intensity [3, 14]. This can be expressed as Fresnel's law

$$. R = \frac{1}{2}\left[\left(\frac{n_1\cos\theta_i - n_2\cos\theta_t}{n_1\cos\theta_i + n_2\cos\theta_t}\right)^2 + \left(\frac{n_2\cos\theta_i - n_1\cos\theta_t}{n_2\cos\theta_i + n_1\cos\theta_t}\right)^2\right] \quad \text{.........................2.1}$$

Where n_1 and n_2 are the refractive indices for the external medium (air) and material respectively, while θ_i and θ_t are incident and the transmitted angle respectively. Using Snell's law of refraction [21, 22]

$$n_1 \sin\theta_i = n_2 \sin\theta_t \quad \text{..2.2}$$

$$\theta_t = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_i\right) \quad \text{...2.3}$$

When the light incident in the direction normal to the medium surface, i.e. $\theta_i = \theta_t = 0^o$, and if the external medium is air $(n_1 = 1)$, and $n_2 = n$ equation (2.1) becomes

$$R = \left(\frac{n-1}{n+1}\right)^2 \quad \text{..2.4}$$

2.12.2. Absorption

Absorption is due to a partial conversion of light energy in to heat, motion or certain vibrations of molecules of light, the absorbing material. Instead of completely transmitting light, an object or a substance can absorb part or the entire incident light, usually converting it into heat.

A substance is said to show general absorption if it reduces the intensity of all wave lengths of incident light nearly with the same amount. Instead many materials absorb some wavelengths while transmitting others, which are called selective absorption. Laser light is monochromatic which is responsible for its selective effects on the given sample medium.

Absorption occurs when the photon frequency incident on the medium matches with the frequency associated with the molecules transition. The ability of a medium to absorb electromagnetic radiation depends on number factors, mainly the electronic constitution of its atoms and molecules, the wavelength of incident radiation, the thickness of absorbing layer, and the internal parameters such as the temperature and /or concentration of absorbing agents [32].

The relationship between the absorption of light in a purely absorbing thickness x, can be found using Beer-Lambert law. In optics, the Beer-Lambert Law is an empirical relationship that relates the absorption and scattering of light to the properties of the material through which light is traveling. When a beam of light is passed through matter in solids, liquids or gaseous states, its propagation is affected by two important ways:

- The intensity will always to a great or lesser extent will decrease as the light penetrates further in to the medium
- The velocity of light will be less in the medium than in free space.

The loss of intensity is chiefly due to absorption and scattering. If monochromatic light is passed through a certain thickness of solid or liquid enclosed in a transparent cell, the intensity of the transmitted light may be much smaller than that of the incident beam of light, owing to absorption. However, the decrease in intensity of the light beam is not only due to absorption. Some of the light passing through the material is scattered, i.e. a fraction of a beam does not continue in its original straight line path but is deflected to other direction due to the fact that the velocity of light in matter differs from that in vacuum [44]. For plane waves the fractional reduction of the beam intensity $\frac{dI}{I}$ is directly proportional to an infinitesimal path length dx in its direction through a homogeneous medium with absorption coefficient μ_a.

$$\frac{dI}{I} = -\mu_a dx \qquad \ldots\ldots 2.5$$

Integrating and evaluating it as definite integral in traversing an infinitesimal thickness x we can find

$$\int_{I_o}^{I} \frac{dI}{dI} = -\mu_a \int_0^x dx \qquad \ldots\ldots 2.6$$

And the reduce intensity (I) can be written as

$$I = I_o \exp(-\mu_a x) \quad \text{...2.7}$$

The absorption coefficient μ_a at a particular frequency can be related with the absorption cross-section σ_a and the number density of molecules ρ in the sample as follows:

$$\mu_a = \rho\sigma_a \quad \text{...2.8}$$

And it can be related again with the concentration c and absorptive as $\mu_a = c\varepsilon_a$ then using the above two relations, the reduce intensity (I) can be rewritten as

$$I = I_o \exp(-\rho\sigma_a x) \quad \text{..2.9}$$

$$I = I_o \exp(-c\varepsilon_a x) \quad \text{...2.10}$$

The absorption coefficient μ_a in equations above can thus be interpreted as the probability that the photon will be absorbed by the medium per unit length. The reciprocal $\frac{1}{\mu_a}$ is called the absorption path length and equal the mean free path a photon travels between successive absorption events. This is the distance required for the intensity (I) of the beam to fall to $\frac{1}{e}$ of the initial intensity (I_o) value. The absorption property of an ensemble of particles is represented by the absorption coefficient $\mu_a\left(mm^{-1}\right)$, defined as

$$\mu_a = \frac{\textit{The total power absorption by particles in unit volume}}{\textit{The intensity of incident power}} = \frac{I_a}{I_o} \quad \text{..........................2.11}$$

2.12.3. Scattering

The scattering of light may be thought of as the redirection of light that takes place when an electromagnetic EM, wave (an incident light ray) encounters an obstacle or non-homogeneity, in our case the scattering particle. It is a fundamental factor in our visual perception of this world's phenomenon, such as the blue sky, red sunsets, clouds, rainbows, snow, fog, milk, and white paint are striking examples of the influence of scattering [25, 28]. When cloud of smoke suspended particles, which has elastically bound charged micro particles, are exposed to electromagnetic waves the particles are into motion or vibration by the electric field. As the EM wave interacts with the discrete particle, the electron orbits within the particle's constituent molecules are perturbed periodically with the same frequency (v_o) as the electric field of the incident wave. The oscillation or perturbation of the electron cloud results in a periodic separation of charge with in the molecule, which is called an induced dipole moment. The oscillating induced dipole moment is manifest as a source of EM radiation, thereby resulting in scattered light. The majority of light scattered by the particle is emitted at the identical frequency of the incident light, a process referred to as elastic scattering. In summary, the above comments describe the process of light scattering as a complex interaction between the incident EM wave and the molecular/atomic structure of the scattering object; hence light scattering is not simply a matter of incident photons or EM waves "bouncing" off the surface of an encountered object [29].

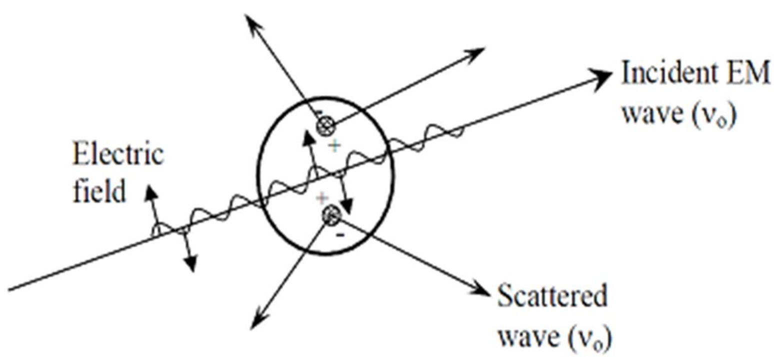

Figure 2. 3: Light scattering by an induced dipole moment due to an incident EM wave.

Unlike absorption, scattering of light occurs at a non-resonance frequency, in which it takes place at frequencies not corresponding to those natural frequencies of particles. The oscillation or perturbation of the electron cloud on the particle results in a periodic separation of charge within the molecule, which is called an induced dipole moment. The oscillating induced dipole moment is manifest as a source of EM radiation, there by resulting in scattered light. The majority of light scattered by the particle is emitted at the identical frequency v_o of the incident light, a process referred to as elastic scattering. Rayleigh and Mie scattering are two types of elastic scattering. While Raman and Brillouin scattering are inelastic scattering in which the frequency of the scattered wave differs from that of incident wave. Rayleigh scattering is applicable to small (smaller as compared to incident wavelength), dielectric (non-absorbing) without a particular bound on particle size, most preferably structures with the same scale to the wave length of incident light wave[30, 43] . The criteria for Rayleigh scattering is that $x \ll 1$ and $|\boldsymbol{m}|x \ll 1$, where x is the dimensionless size parameter given by the expression

$$x = \frac{2\pi\alpha}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2.12$$

where α , is the spherical particle radius and λ is the relative scattering wave length defined as

$$\lambda = \frac{\lambda_o}{m_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

where λ_0 is the incident wave length in vacuum, m_0 represents the refractive index of the medium and m is the refractive index of the scattering particle . Assuming the sample is homogeneous so that the scattering particles are uniformly distributed throughout its entire body. The non-scattered components of light I_x through a non-absorbing sample of thickness $x = L$, can be related with scattering coefficient μ_s as

$$I_x = I_o \exp(-\mu_s x) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

The scattering properties of an ensemble of particles are expressed by the scattering coefficient, $\mu_s (mm^{-1})$

The scattering coefficient μ_s at a particular frequency can be related with the scattering cross-section s and the number density of molecules in the sample as

$$\mu_s = \delta_s \rho \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

The scattering path length $\frac{1}{\mu_s}$ is the average distance the photon travels between successive scattering events which are known as mean free path. When a photon that is incident along a direction described by a unit vector, ŝ experiences a scattering event, the angular probability of its being scattered in to the direction, $\hat{s}'$, with an angle θ is given by the normalize phase function p (ŝ, $\hat{s}'$). It can be expressed as a function of the cosine of the scattering angle $= \cos\theta$.

The mean cosine of the scattering angle called anisotropy factor, g, and it is a measure of degree of scattering which can be expressed as follows [29]

$$g\langle\cos\theta\rangle = \int_{4\pi}(p\cos\theta)d(p\cos\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.16$$

If g is positive, the phase function is predominantly forward; if g is negative, backward scattering dominates. A constant phase function results in an isotropic scattering (g=0). Hence the transport (or reduced scattering coefficient), μ_s is defined as

$$\mu_s^{'} = \mu_s(1-g)' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.17$$

In most turbid medium absorption and scattering may be present simultaneously. Their total attenuation coefficient can be expressed as a combination of scattering and absorption coefficients of the medium by

$$\mu_t = \mu_a + \mu_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.18$$

This tends us to express the total mean free optical path of incident photons in the medium as

$$L_t = \frac{1}{\mu_t} = \frac{1}{\mu_a + \mu_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.19$$

In some cases, either μ_a or μ_s may be negligible with respect to each other, it is important to realize the existence of both process and the fact that usually both are operating also it is very convenient to define additional parameter, the optical albedo, α

$$\alpha = \frac{\mu_s}{\mu_t} = \frac{\mu_s}{\mu_a + \mu_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.20$$

For $\alpha = 0$, attenuation is exclusively due to absorption only, whereas $\alpha = \frac{1}{2}$, the total attenuation coefficient $\mu_t = 2\mu_a = 2\mu_s$ in equation above or/and which $\mu_a = \mu_s$ means the coefficients of absorption and scattering are of the same magnitude. In general, both effects may take place but they may occur in variable ratios [26, 34].

2.13. Intensity Distribution of Scattering of Light and Airy Disk

In most turbid mediums photons are preferably scattered in the forward direction. The intensity of the scattered light is a function of the wave length λ, the scattering angle θ, the particle size diameter d, and the relative index of refraction n of the particle and the surrounding medium. Symbolically, then,

$$I_s = I(\lambda;\theta;d;n) \qquad \text{...2.21}$$

During the interaction of laser light with particles of the medium, either the particle has larger or smaller in size as compared to the incident light wavelength, Mie scattering theory describes the phenomenon by considering the optical properties (refraction and absorption) of the particles. The smaller the particles are the higher is the contribution of refraction and absorption to the light scattering pattern. For the measurement of particle size distributions inside the given sample medium, therefore, the scattering intensity distribution pattern should be detected over the entire angle range around the sample and it will looks like as shown in figure (2. 4)

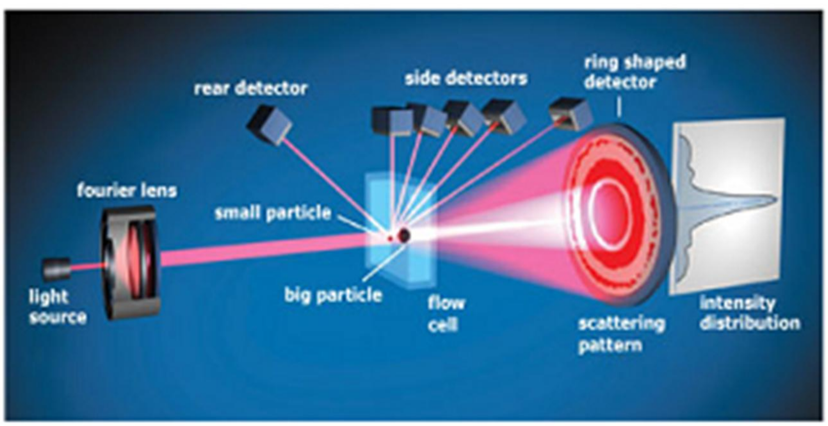

Figure 2. 4: Intensity distribution profile of light propagation through medium (airy disk)

The scattering intensity distribution pattern resulting from a scattering of laser light has a bright region in the center, known as the Airy disk which together with the series of concentric bright rings around is called the Airy pattern. The dark ring pattern between two bright regions show that the detected minimum intensity distribution. The diameter of the airy disk, d, at the center of the distribution corresponds to the particle size of the scatterer in the medium [22, 28], that is helpful for calculating the dimensionless size parameter x, which can be expressed using diffraction equation as follows

$$d = \frac{1.22\lambda}{\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.22$$

Where θ measured from the incident transmission line to the first detected minima. The particle size calculation from the scattering intensity distribution pattern is useful for investigation of the optical properties of the medium [29, 36].

The particle size calculation from the scattering intensity distribution pattern is useful investigation of optical properties of the medium Niger oil sample.

2.14. Basic design of a Laser Particle Size

Basically the design is always the same: A light beam, mostly supplied by a laser, shines through the sample to be measured and behind it, the intensity distribution caused by the scattering is picked up with a detector. Here already, it shall be mentioned, that the particle collective to be measured should be available sufficiently diluted and should not form clusters or even better said should not create agglomerates. Then the measured intensity distribution shows a system of numerous more or less concentric rings, which their spacing correlates with the particle size.

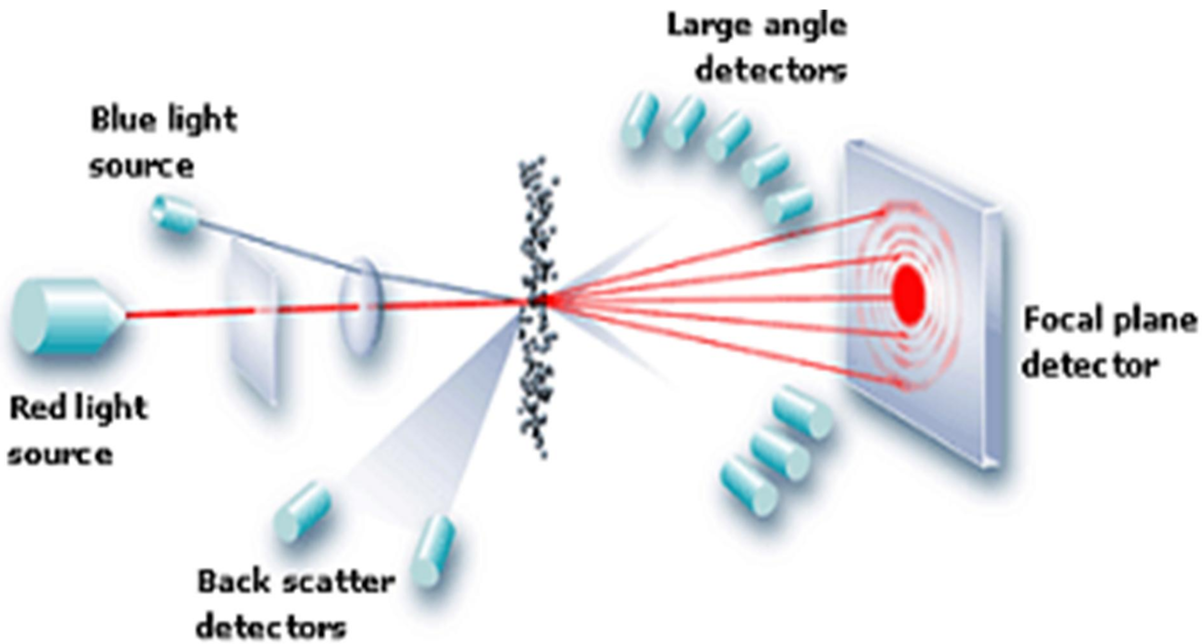

Figure2. 5: Basic Design of a Laser Particle Size [37]

2.15. Radiative Transfer Equation (RTE)

The physical phenomenon of energy transfer (photon transfer) in the form of electromagnetic radiation is called Radiative Transfer. The propagation of radiation through medium is affected by absorption, emission and scattering processes. The equation of radiative transfer describes these interactions mathematically. The fundamental quantity which describes a field of radiation is nowadays called the spectral radiance, traditionally called the specific intensity. The flow of radiation energy through a small area element in the radiation field can be characterized by radiance $L\left(\vec{r}, \vec{s}, t\right)\left(\frac{w}{m^2 sr}\right)$, which is defined as energy flow per unit normal area per unit solid angle per unit time. Here, r denotes position, ŝ denotes unit direction vector and t denotes time. The RTE simply says that as a beam of radiation travels, it loses energy to absorption, gains energy by emission, and redistributes energy by scattering. In RTE, Optical properties such as refractive index n, absorption coefficient μ_a, scattering coefficient μ_s, and scattering anisotropy g, are taken as time-invariant but may vary spatially, and scattering is assumed to be elastic. The integro-differential form of the equation for radiative transfer is given as [22].

$$\frac{\partial L\left(\vec{r},\hat{s},t\right)\Big/ v}{\partial t} = -\hat{s}\cdot\vec{\nabla} L\left(\vec{r},\hat{s},t\right) - \mu_t L\left(\vec{r},\hat{s},t\right) + \mu_a \int_{4\pi} L\left(\vec{r},\hat{s}',t\right) P\left(s^{-1},\hat{s}\right) d\Omega' + S\left(\vec{r},\hat{s},t\right) \quad ..2.23$$

Equation (2.23) describes the change of radiance, $L\left(\vec{r},\hat{s},t\right)$ at position $\vec{r}$, in the direction of the unit vector $\hat{s}$. Where v is the speed of light in material medium as determined by the relative refractive index $n = {}^{v}\!/_{c}$, $\mu_t = \mu_a + \mu_s$ is the total attenuation coefficient, $S\left(\vec{r},\hat{s}'t\right)$ is a radiation source and $P(\hat{s},\hat{s}')$ is scattering phase function representing the probability of light with propagation direction $\hat{s}$ being scattered in to solid angle $d\Omega$ around $\hat{s}'$. In most cases, the phase function depends only on the angle between the scattered $\hat{s}'$ and incident $\hat{s}$ direction, i.e. $P(\hat{s},\hat{s}') = P(\hat{s}',\hat{s})$. The scattering anisotropy can be expressed as $g = \int_{4\pi} (\hat{s}',\hat{s}) P(\hat{s},\hat{s}') d\Omega$

The diffusion equation is given as

$$\frac{\partial \Phi\left(\vec{r},t\right)}{c\partial t} + \mu_a \Phi\left(\vec{r},t\right) - \nabla.\left[D\nabla\Phi\left(\vec{r},t\right)\right] = S\left(\vec{r},t\right) \quad ....2.24$$

$$where \;\; D = \frac{1}{3\left(\mu_a + \mu_s^{/}\right)} \; is\, the\, diffusion\, coefficent$$

2.16. Solutions of the diffusion equation with point sources in an infinite homogeneous media

For simple case, using a short-pulsed point in an infinite homogeneous medium, the diffusion equation can be solved for fluence rate. The source term in the diffusion equation (2.24) above becomes $S\left(\vec{r},t,\vec{r}'t'\right) = \delta\left(\vec{r}-\vec{r}'\right)\delta(t-t')$ where $\vec{r}, and\, \vec{r}'$ are the position at which fluence rate is measured and the position of the source respectively. And the pulse peaks at time t'.

Thus the solution can be presented as of the following

$$\Phi\left(\vec{r},t,\vec{r}',t'\right)=\frac{v}{\left[4\pi Dv(t-t')\right]^{\frac{3}{2}}}\exp\left[\frac{\left|\vec{r}-\vec{r}'\right|^{2}}{rDv(t-t')}\right]\exp\left[-\mu_a v(t-t')\right] \quad \ldots 2.25$$

The exponential decay in fluence rate due to absorption in accordance with Beer's law is expressed in the equation 2.25 above with the term exp $\exp\left[-\mu_a v(t-t')\right]$ and the other terms represent broadening due to scattering.

Taking time variation out of the diffusion equation gives the following for the time independent point source $S\left(\vec{r}\right)=\delta\left(\vec{r}\right)$:

$$\Phi\left(\vec{r}\right)=\frac{1}{4\pi Dr}\exp\left(-\mu_{eff}r\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.26$$

Where, $\mu_{eff}=\sqrt{\frac{\mu_a}{D}}=\sqrt{3\mu_a\left(\mu_a+\mu_s^{\prime\,'}\right)}$ is the effective attenuation coefficient and indicates the rate of spatial decay in fluence.

In general, light scatters whenever encounters a physical object. Its scattering behavior depends on its wavelength, the particle optical properties relative to the surrounding medium the complex refractive index as well as the size of the object. For particles much larger than the light wavelength, geometric optics is a good approximation of the scattered field; for particles much smaller than the wavelength, one can use the Rayleigh scattering formula. However, for particles whose sizes are on the order of the wavelength, there is no simple approximation. Light scattering from such particles is described by the Mie solutions to Maxwell equations. The remarkable feature of Mie theory is that it predicts the angular dependence of scattered intensity, as illustrated in Fig. 2.1. Since this angular dependence is very sensitive to the particle size, Mie scattering has been used as an accurate sizing method of microspheres [16, 17, and 22]. In previous undergraduate-level experiments, particles suspended in liquid were used to perform Mie scattering measurements, assuming that the light scattering behavior of the suspension is the same as that of a single particle.

In a solution of scattering spheres, if the concentration of spheres is not too high, we may approximate their collective scattering as resulting from a large number of independent scatters, and as such, the scattering curve should simply be some multiple of the curve for a single sphere. A concentration of such spheres is said to be in the "single scattering regime." the theoretical expression for the intensity of light scattered from a spherical particle to a given angle, the angular scattering distribution, is given by the Mie theory.

Formal light scattering theory may be categorized in terms of two theoretical frameworks. One is the theory of Rayleigh scattering (after Lord Rayleigh) that is, strictly speaking as originally formulated, applicable to small, dielectric (non-absorbing), spherical particles. The second is the theory of Mie scattering (after Gustav Mie) that encompasses the general spherical scattering solution (absorbing or non-absorbing) without a particular bound on particle size. Accordingly, Mie scattering theory has no size limitations and converges to the limit of geometric optics for large particles. Mie theory, therefore, may be used for describing most spherical particle scattering systems, including Rayleigh scattering. However, Rayleigh scattering theory is generally preferred if applicable, due to the complexity of the Mie scattering formulation. The criteria for Rayleigh scattering are that $x \ll 1$ and $|m|\, x \ll 1$, where x is the dimensionless size parameter given by the expression:

$$x = \frac{2\pi a}{\lambda} = \qquad \text{.......... 2.27}$$

Where a is the spherical particle radius, and λ is the relative scattering wavelength defined as

$$\lambda = \frac{\lambda_o}{m_o} \qquad \text{.......... 2.28}$$

Where λ_o is the incident wavelength with respect to vacuum, and m_o represents the refractive index of the surrounding medium.

$$\text{Absorption coefficient} = \frac{4\pi k}{\lambda} \qquad \text{.......... 2.29}$$

It is noted that the value of k is never exactly zero for any material, but materials with a value approaching zero are termed dielectrics. Light scattered by particles with sizes on the order of the wavelength is described using Mie theory. Mie scattering is very sensitive to the scatter's size, as well as the scattering angle. As a result, Mie scattering can be used to measure the size of microspheres accurately. Figure 2.5, shows the spherical coordinate scattering geometry used for Mie and Rayleigh light scattering corresponding to a single incident light ray on a single spherical particle. Using this coordinate system, the scattering parameters may be defined for the Rayleigh and Mie solution.

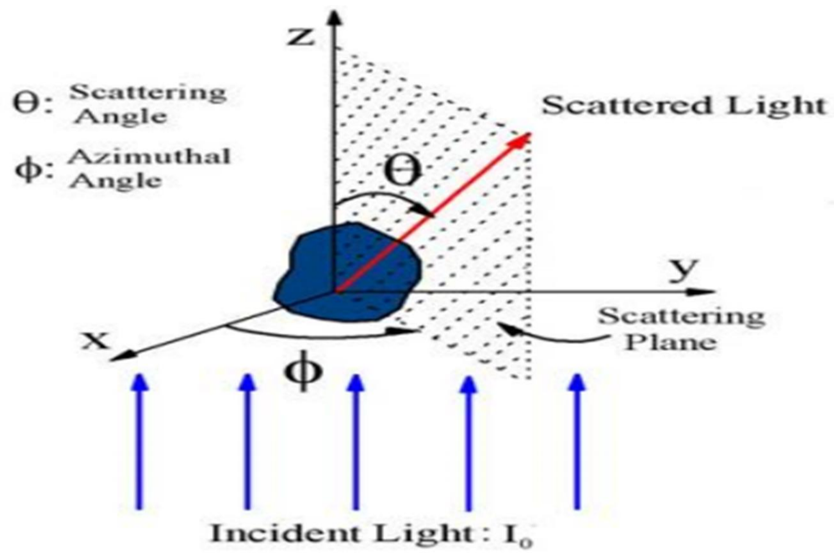

Figure 2. 6: Coordinate geometry for Rayleigh and Mie scattering [45]

2.17. Mie Scattering Theory

Mie Theory is a pretty complex mathematical theory describing the complete profile of Scattering but has some essential condition which needs to be fulfilled

- Incident light of only a single wavelength is considered.
- No dynamic scattering effects are considered.
- The scattering particle is isotropic.
- There is no multiple scattering.
- All particles are spheres.
- All particles have the same optical properties.
- Light energy may be lost to absorption by the particles [46].

3. RESEARCH METHODOLOGY

3.1. Materials and Methods

This Chapter will explain the material and methods going to use in the work. The first section of this Chapter describes the various samples, chemical and instruments used to carry out this chapter. In the second section of this chapter the different methodologies and methods applied to investigate optical properties and particle size edible oil sample in relation to quality will present.

3.1.1. Materials

The materials used in this experiment are as follows; cylindrical glass cuvette with diameter 15 mm and rectangular glass cuvette 10 mm in diameter and sample edible oil.

The laboratory apparatus and instrument used for this work are the following

35 mw He-Ne laser at 632.8nm wave length, chopper, chopper controller, collimator, photodiode detector, lock-in amplifier, stepper and computer interface programs for instrumental control, data recording and file handling operation.

3.1.2. Methods

The steps of preparing sample of solutions for this experimental work are as follows.

All glass wares were thoroughly cleaned, rinsed with distilled water and dried before used. In each five glass of measuring tube equal amount of solvent (hexane) is poured. Then after that the solvent is diluted by adding the solute (Niger oil) 2 ml in the first glass tube, again adding the Niger oil to the glass tube containing the solvent with gradually equal increase in volume in all five glass tube containing the solvent to dilute it to get a series of variable concentration for collimated transmission and fluency rate measurements. The proportions of concentration are expressed in the table below.

Table 3. 1: Concentration of prepared sample solution

Soluti on	A	B	C	D	E
Volume of solute (ml)	2	4	6	8	10
Volume of solute (ml)	20	20	20	20	20
Concentrations (%)	10	20	30	40	50.00

Figure 3. 1: Photograph of the prepared solution for the experiment

Lock-in Amplifier

In its most basic form a lock- in amplifier is an instrument with dual capability. It can recover signals in the presence of an over whelming noise background or alternatively, it can provide high resolution measurements of relatively clean signals over several orders of magnitude and frequency. However, modern instruments offer far more than these two basic functions and this increased capability has led to their acceptance, in many scientific disciplines, as unit which can provide the optimum solution to a large range of measurement problems. The modern lock –in amplifier will function as an AC Signal Recovery Instrument, a vector voltmeter, a phase meter, a Spectrum Analyzer, a Noise Measurement Unit and much more. It is this visibility, available in a single compact unit, which makes the lock-in amplifier an invaluable addition to any laboratory. This technical Note describes ”building blocks” of the lock-in amplifier so that the user and potential user may better understand how the instrument work and how the choices made in their design affect their performance.

3.3. Optical measurement techniques

The study was focused on the measurement and calibration of the optical properties of the diffusing medium such as absorption, scattering, reduced scattering, effective attenuation Coefficient and an isotropic factor. In measuring the optical properties and particle size of the diffusing medium three phases of measurement were considered. These are collimated transmission measurement, fluence rate measurement and angular distributions of intensity measurement.

Phase-I: Collimated transmitted measurement

The collimated transmitted light that passes through the sample must be passed through the collimator. The aim of passing the collimated transmitted light through collimator is that to avoid the scattered light from entering the detector. Figure 3.2 shows how it works.

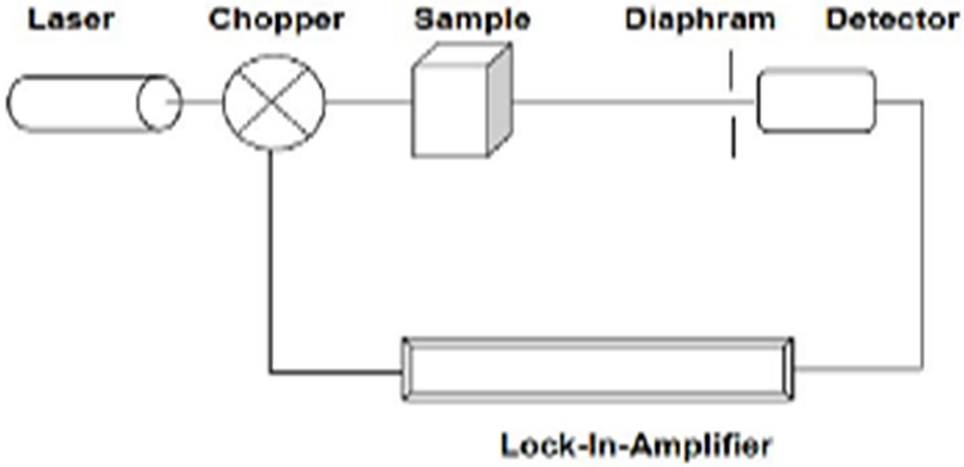

Figure 3. 2: Schematic diagram of the experimental set up for transmission measurement.

Figure 3. 3: Photograph of the experimental set up used for transmission measurement.

The transmitted (not scattered) light through the oil sample was detected with photo diode detector connected to the lock-in amplifier. The lock-in amplifier again connected to the chopper, which is fixed for all phase measurements, to purify the signal from other interfering frequency noise signals. The photo-diode detector used had a sensitivity curve in visible range of wavelengths. The initial intensity of light I" in which it was first passed though the sample cell containing only hexane was recorded. This was done to compensate for refractive index mismatches between the external medium (air) and the surface of the cell. Then the corresponding intensities of light I, passing through different concentrations of the sample in the light path was measured. This was done by taking a small sample solution from diluted sample prepared first with gradually increased concentrations by 2 ml (10 %) until 10 ml (50 %) values were reached. The collimated transmission method is used to calculate the total extinction coefficient of the diffusing medium ε_t. It was also used to investigate the optical properties of the sample and this would be done by applying Beer Lambert Law.

$$I = I_0 \exp(-\mu_t L) \quad \text{.................................3.1}$$

where $\mu_t(\mu_t = c\varepsilon_t)$ is the total attenuation coefficient, ε_t is the total extinction coefficient, c is the concentration of the sample and L is thickness for total path length through the sample in the cuvette.

Phase-II: Fluency Rate Measurement

In this method the multi angular distance measurement fluence rate or emitting in which the rate total amount of photon crossing over surface of unit cross section, inside the highly diffusing medium was performed. Figure 3.4 shows the set up. He-Ne laser beam was incident on a cylindrical sample cell of diameter 15 mm containing hexane only to measure the initial light intensity I_o.

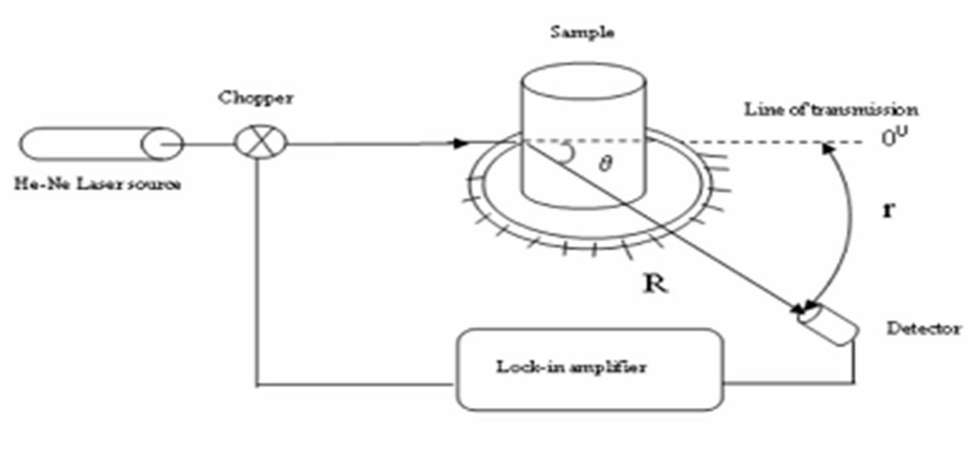

Figure 3. 4: Schematic diagram of multi-angular distance measurements set up measuring fluency rate

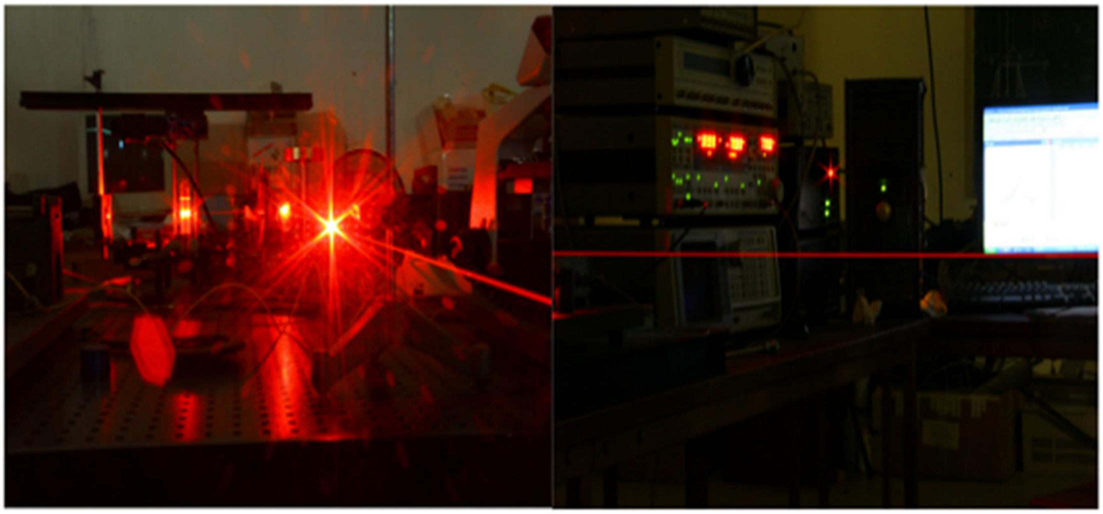

Figure 3. 5: Photograph of experimental set up for multi-angular distance measurement of fluency rate

The corresponding intensities of laser light I for a series of gradually increased variable concentrations were measured. The concentrations of the samples used in these measurements were taken from the first prepared solutions with gradually increased concentration from 2.10% to 10.5 %. For variably concentrated oil samples of the added amount concentration, the fluence rate was measured by varying the angle from 9^0 to 54^0 in steps of 9^0. The angular measurement was taken from the line of transmission in both clockwise and counter clocking wise directions. The source to detector distance 23 cm was kept constant. The curve distance from the line of transmission to the detector at any angle θ is $r = R\theta$ which measured using spectrometer scale. The fluece rate as a function of the curve distance between the line of transmission 0^0 and detector as it mentioned in the radiative transfer equation in chapter two is defined as

$$\phi(r) = \frac{1}{4\pi D r} \exp(-\mu_{eff} r) \qquad \text{.............................3.2}$$

Where D is the diffusion coefficient defined by D=$\frac{1}{3(\mu_a + \mu_s)}$ for the medium having high albedo (α) and by rearranging the above fluence rate equation it can be written as follows:

$$\ln(\phi(r)r) = -\mu_{eff}\, r + \ln\frac{3\mu_s^{'}}{4\pi} \qquad \text{.......................................3.3}$$

After the effective attenuation coefficient was found, it was possible to find the reduced scattering coefficient μ_s' using the equation $\mu_{eff}^2 = 3\mu_a(\mu_a + \mu_s') \approx 3\mu_a\mu_s' \rightarrow$ for $\mu_a \le \mu_s'$ the anisotropy factor (g) can be calculated using the relations $\mu_s' = (1-g)\mu_s$ for a specific concentration.

Phase-III: Angular Distribution of Intensity Measurements

In this phase we should be measuring the incident He-Ne laser beam intensity on a sample cell containing hexane only. A 2 ml oil sample solutions was diluted by hexane to make a 10 % by volume 20 ml solution and by taking 2 ml sample from these 20 ml solution the intensity measurement were carried out. The intensity of light was detected and measured three times by varying the angle around the sample the line of transmission 0^0 and clockwise and counterclockwise using the photo diode detector of the spectrometer.

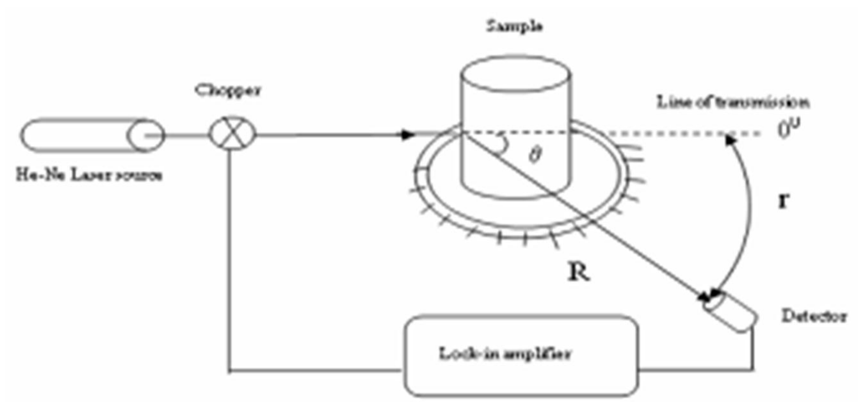

Figure 3. 6: Schematic diagram of experimental set up for angular distribution of intensity measurement

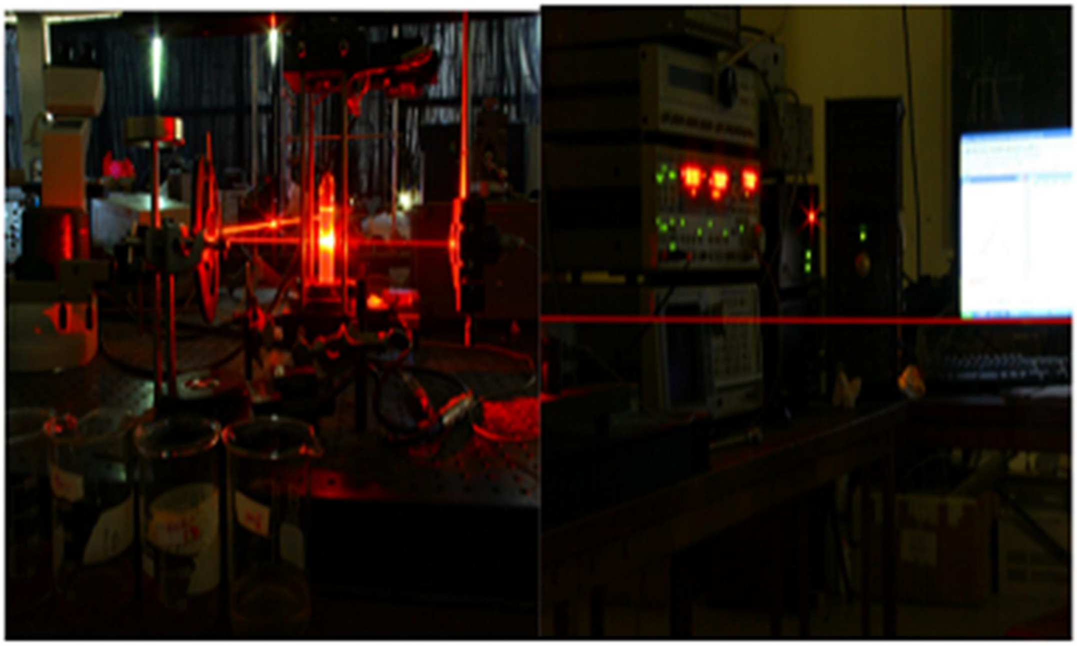

Figure 3. 7: Photograph of experimental set up for angular distribution of intensity measurement.

The Airy disk (or a diffuse circular disk) would be from the distribution of detected light intensity rather than forming a bright dot as image when light from He-Ne laser source passes through spherical particle. The diameter of the Airy disc corresponds to the diameter of the scattering particle. The size of the particle can be calculated from the angle measurement and using the diffraction equation

$$d = \frac{1.22\lambda_0}{\theta} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

The spherical scattering particle size (diameter) can be computed using the value of d. θ in the above expression represent the angle from the transmission line 0^0 to where the first minima occur. The particle size parameter can then be calculated

$$x = \frac{d\pi}{\lambda_0} n_{med} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

where n_{med} is the refractive index of the surrounding medium at room temperature and λ_0 is the wavelength of the incident He-Ne laser beam. A Mie scattering theory of particle size calculation again yields the scattering efficiency Q_s of the scatterer in the solution to know the amount of efficient cross- sectional area for scattering phenomena as follows

$$Q_s = \frac{\mu_s}{\rho_s A} \quad \text{......................................3.6}$$

Where A is the true geometrical area of the scatterer and ρ_s is the particle number density which relates the scattering cross sectional area σ_s to the true geometrical area $A = \pi r^2$ of the spherical particle by the equation

$$\sigma_s = \frac{\mu_s^{'}}{\rho_s} \quad \text{..3.7}$$

After the determination of the optical properties of the diffusing medium such as the absorption, scattering, reduced scattering, effective attenuation coefficients and anisotropy factor was tried to relate with the quality of Niger oil. This gives information about the particle size dependency quality of edible oil and this will be discussed briefly in the discussion part of the next chapter (Chapter four).

3.4. Mie Scattering Calculator

However the mathematical expressions for Mie solutions (Maxwell's equations) that are used to calculate the particle size and other parameters are complex and difficult to use, **the Interactive Mie Scattering Calculator Microsoft ware by Scott Prahl at** **http://omlc.ogi.educ/calc/mie calc.html is used on-line f**or it is simple to use and produces outputs results fast. This calculator is used to calculate the value of required output parameters from input parameters which have calculated or known values first. The Interactive Mie Scattering Calculator Microsoft ware is used to calculate the optical parameters. This could be happen because the interactive calculator has been installed by mathematical equations that are used in Mie theory. For a single spherical particle, the Mie theory gives the optical parameter, like extinction, scattering and absorption cross-sections, the scattering amplitudes and phase matrix. It does the calculation in fast and gives accurate values for each parameter.

4. RESULTS AND DISCUSSION

In this Chapter the results found from the three phases of experiments are presented independently. The analysis was performed by Beer-Lamberts Law and RTE in the discussion approximation theory. Graphs and some algebraic calculations are used in the discussion to show the relationship between various quantities. The relationship between concentration and absorbance was used to calculate the extinction coefficient of the given oil sample medium. Curve distance and fluency rate graph is used to determine scattering, reduced scattering and absorption coefficients and anisotropy factor. The diffraction equation was used to calculate the particle size and scattering parameter of the sample.

4.1. Total Extinction Coefficient

The collimated transmission measurement phase of the experiment, section I phase is used to calculate the total extinction coefficients of the prepared oil sample medium. In the diluted samples, the concentration of oil was varied from 10 % to 50 % with 10 % variation by the volume. From the total sample 16 ml sample having a concentration increment of 0.4 % (0.4 % to 2.0 %) were taken by rectangular cuvette for the measurement. The initial incident intensity I_o was measured with the sample cuvette containing only the solvent, which was hexane and found to be $I_o = 125.52\ a.u$ .Then the corresponding intensities of light I passing through different concentrations of the sample oil were measured. The experimental results for the sample with different concentrations of prepared sample solution were shown in Table 4.1 Using Beer-Lamberts Law equation 3.1, the relationship was plotted for attenuation coefficient against concentration. The slope of straight line represents the total extinction coefficient ε_t which is the attenuation of the intensity of light due to absorption and scattering in the sample. The value was analyzed and calculated by origin 8.0 software and found to be $\varepsilon_t = 3.52x10^{-3}$ from the graph for this sample.

Table 4. 1: Transmission intensity measurement for different concentration of oil sample

Oil sample	Concentration (%)	Intensity	$\frac{1}{L}\ln\left(\frac{I_O}{I}\right)$
Niger oil	0	125.52	0.00
	0.4	123.35	0.0017
	0.8	122.42	0.0025
	1.2	120.63	0.0040
	1.6	118.71	0.0056
	2.0	116.53	0.0074

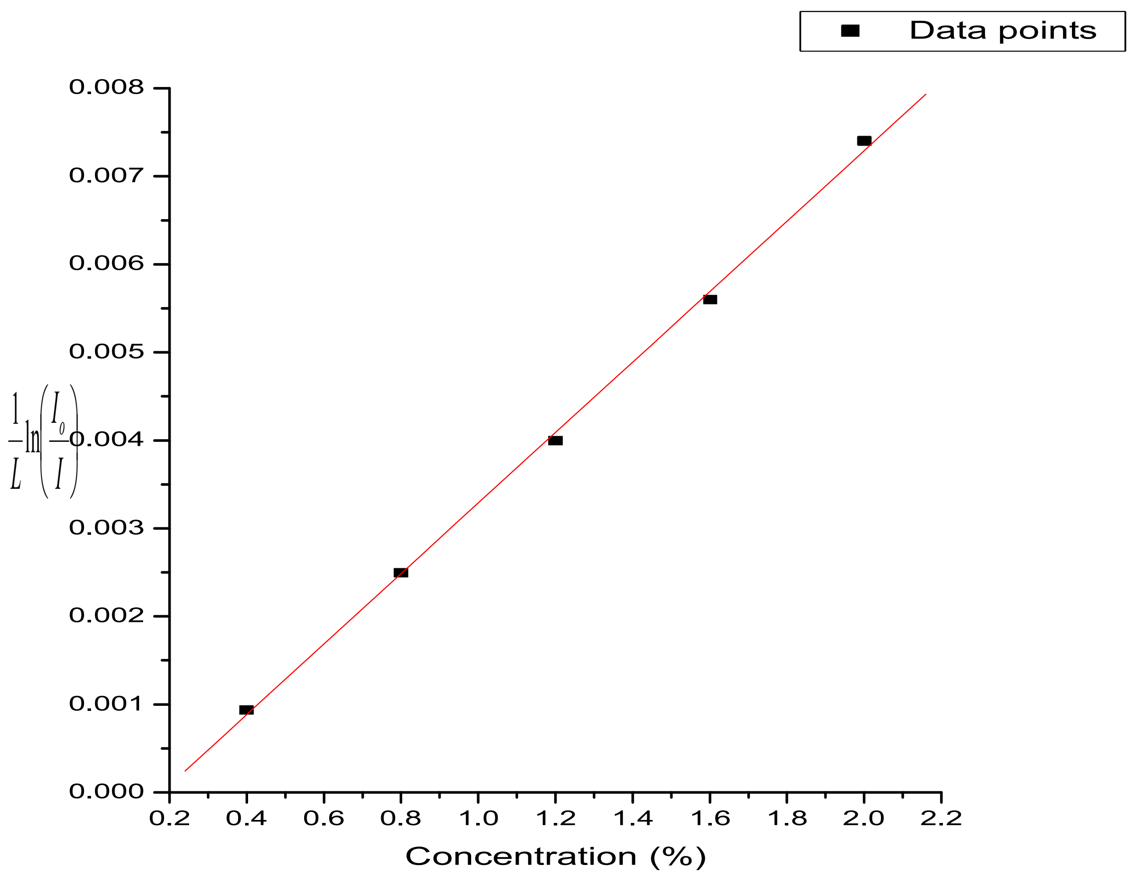

Figure4. 1: Graphs of attenuation coefficient versus concentration of oil sample used in this experiment

Generally if we take different species of oil it can have different attenuation coefficient in the given wave length of light. This generalization intern led us to deduce that the quality of different species of edible oil can be affected by this property with relation to absorption and scattering coefficients. The total attenuation coefficient μ_t, of Niger oil sample was calculated using equation 3.1. In this step of experiment we use the sample and the corresponding intensity for the given sample was detected as $I = 116.53\ a.u$ and the result of calculation from the experiment gives us the total attenuation coefficient $\mu_t = 6.04x10^{-3}\,mm^{-1}$ for this sample experiment. The graph indicates that the sample of edible oil used in this experiment has albedo constant or it has no absorption coefficient $\mu_a = 0$ for this given wavelength value of light, in which 633 nm He-Ne laser. This shows that the results are in good agreement with the diffusion equation approximations in the literature in which high albedo medium is necessary to use those approximation.

4.2. Absorption, scattering and reduced scattering Coefficients and Anisotropy Factors

Multi angular distance or fluence rate measurement method was carried out to investigate absorption, scattering and reduced scattering coefficient and anisotropy factors of used oil sample medium. This phase measurement results were analyzed based on the solution of the radiation transport equation (RTE) for a point source in an infinite medium with diffusion equation (DE) approximations. The concentrations of oil were varied from 2 ml to 10 ml in volume ratio for which the fluence rate intensity $\phi(r)$ was attenuated. The raw data of the measurements were presented in Table 4.2 and their corresponding graphs for $\ln(\phi(r)\,r)$ versus r are shown as figure 4.2.

Table 4. 2: Fluence rate measurement raw data of oil sample used in the experiment

Sample	angle (θ^0)	Distance $r = R\theta$ (mm)	$\phi(r)$ ΔC=2.10 %	$\phi(r)$ $\Delta C =$ 4.20 %	$\phi(r)$ $\Delta C =$ 6.30 %	$\phi(r)$ $\Delta C =$ 8.40 %	$\phi(r)$ $\Delta C =$ 10.50 %
Niger oil	9	17.27	34.36	50.01	51.43	52.81	65.75
	18	34.54	16.52	24.01	25.36	26.13	32.29
	27	51.81	10.45	15.23	10.27	17.32	20.46
	36	69.08	7.69	10.52	11.25	12.42	14.38
	45	86.35	5.83	7.81	8.52	9.12	10.87
	54	103.68	4.63	5.92	6.48	7.37	8.24

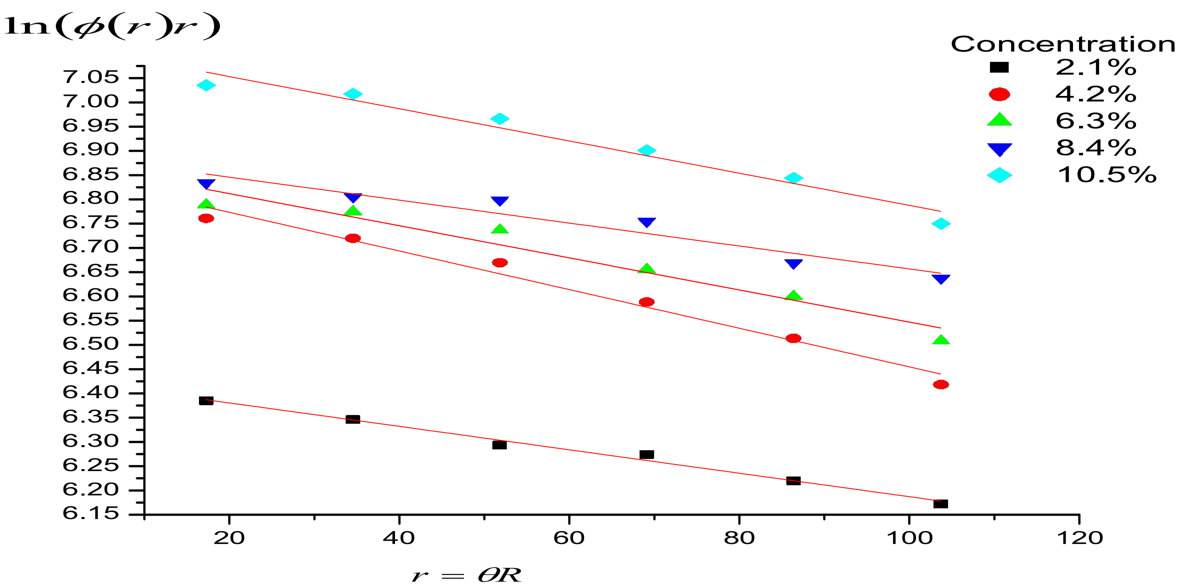

Figure4. 2: Graph for fluence rate measurement $\ln(\phi(r)\, r)$ versus r for edible oil sample used in the experiment.

From the graph it can be observed that the fluence rate increases as the concentration of the medium (Niger oil) increases. The lower line from the graph signifies measurements made with lower concentration of oil sample medium in hexane solution. The slopes of curves in the graph are increasing according to the increase in concentration of oil sample. This indicates that the samples of oil used in this experiment have high albedo or it has no absorption coefficient ($\mu_a = 0$) for this given wavelength value of light in which 632.8 nm He-Ne laser. This shows that the results are in good agreement with the diffusion equation approximations in the literature in which high albedo medium is necessary to use those approximations. To calculate the effective attenuation coefficient μ_{eff} and reduced scattering coefficient μ_s' from the slope graphs and equation 2.9 respectively, a curve with specific concentration of the scatterer 6.3 % by volume is selected from samples of oil graphs. The evaluation of the slope of $\ln(\phi(r)\, r)$ as a function of distance r, give us the effective attenuation coefficient $\mu_{eff}^2 = 3\mu_a\mu_s'$ which intern is used to find the reduced scattering coefficient. $\mu_{eff}^2 = 3\mu_a\mu_s^{'}$, the $\mu_s^{'}$ is simply proportional to the concentration of scatterers, whereas the absorption coefficient in the scattering medium is due to only the absorption of the hexane used for dilution which has an absorption coefficient of $3.26x10^{-4}$ at 632.8 nm wave length. Since $\mu_a = \mu_{as} + \mu_{ah}$ and $\mu_{as} = 0$ where μ_{as} and μ_{ah} are the absorption due to both scatterer and hexane respectively. The reduced scattering coefficient μ_s' of oil sample is presented in table 4.3 by using $\mu_s^{'} = \frac{\mu_{eff}^2}{3\mu_{ah}}$. Considering the loss in intensity due to reflection is minimum, the total extinction coefficient is as a result of absorption and scattering , and since the absorption of coefficient of scatterer is zero $(\mu_a = 0)$, the total extinction coefficient is equal to the extinction coefficient due to scattering only ($\varepsilon_t = \varepsilon_s$). Hence multiplying ε_s which is obtained using phase-**I** measurement results of the experiment, with concentration C results in the scattering coefficients μ_s of the scatterer. Using this value and the value obtained for the reduced scattering coefficient, the magnitude of the anisotropy factor g=0.92692 for Niger oil sample was computed and implies forward scattering. All the results of necessary parameter calculations are summarized in table4.3 as follows:

Table 4. 3: Summary for calculated values of different optical properties of oil sample used in the experiment

Oil sample	C (%)	$\mu_{eff}(mm^{-1})$	$\mu_s^{'}(mm^{-1})$	$\mu_s(mm^{-1})$	μ_t	g
Niger oil	6.30	$3.31x10^{-3}$	0.0707	0.96831	0.96831	0.92692

Since the total attenuation coefficient can be expressed as a combination of scattering and absorption coefficients of the medium is given by $\mu_t = \mu_a + \mu_s$ *and* $\mu_t = \mu_s$, as it is shown in the table 4.3 above, the value of absorption coefficient $\mu_a = 0$. As a result absorption efficiency is also zero $(Q_a = 0)$. This implies that there is no light absorption occurs by the scatterer (Niger oil). So, the edible oil used as the sample has good quality.

4.3. Particle Size Measurement Result

Determination of diameter (or particle size) of the scattering particle and particle size parameter x can be performed using the results of the third phase measurements of the experiment, angular distribution of intensity measurements. A 2 ml concentration by volume of sample was taken by rectangular cuvette from 6.51ml solution to get a volume fraction of f_v =0.0016. And this used to calculate the particle number density ρ_s of the scatterer in the sample solution when it is divided by the true geometrical volume of the scatterer. The particle number density ρ_s intern is used to calculate the scattering efficiency Q_s and the scattering cross-sectional area σ_s using equations 3.6.

The graph of symmetric angular distribution of intensity measurement of edible oil used in the experiment has been drawn below.

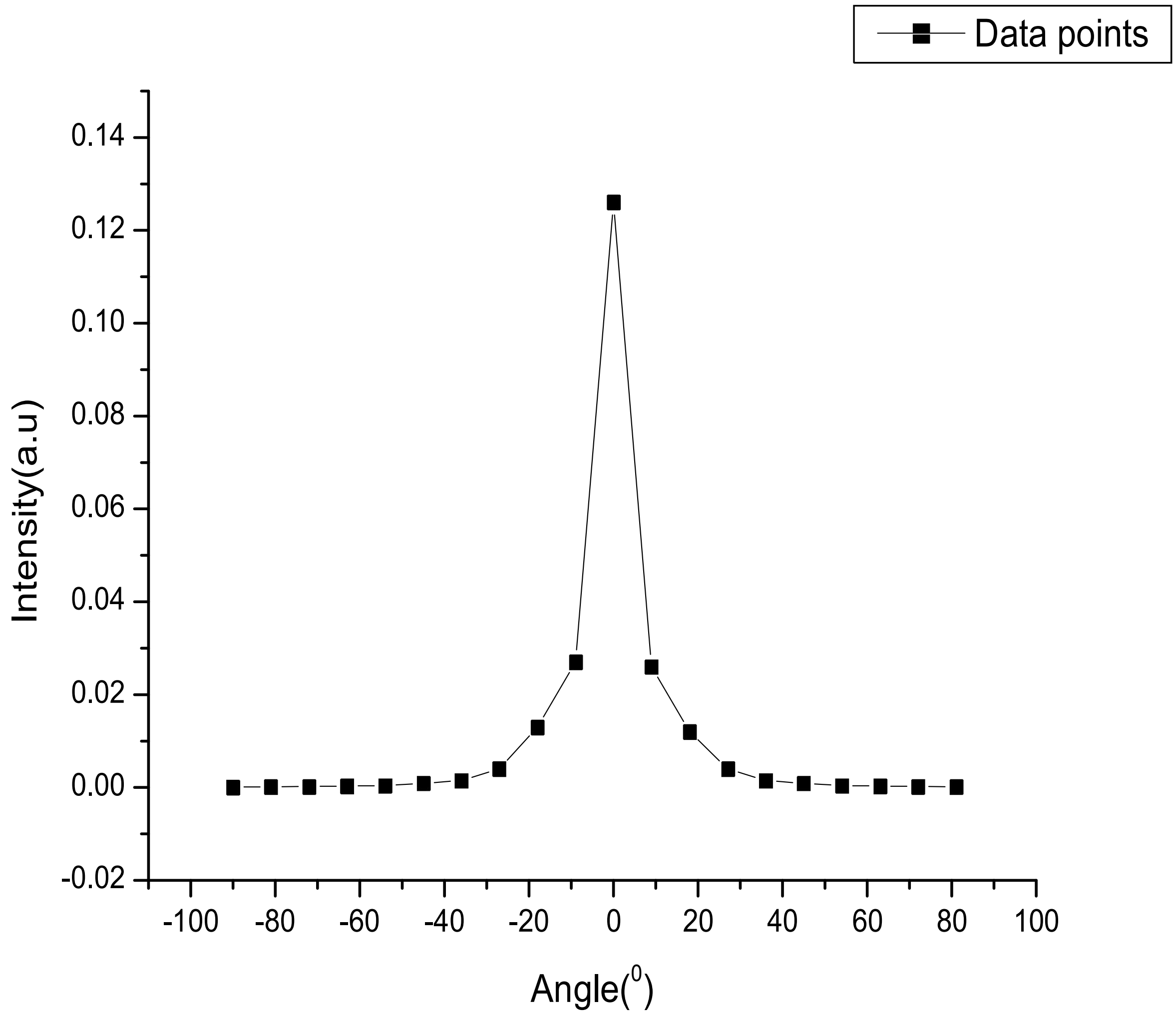

Figure 4. 3: Graph of symmetric angular distribution of intensity measurement of edible sample used in the experiment.

In this experiment, the intensity distribution is symmetric and centered at 0^o and the Airy pattern and airy disc is formed around this center. Using equations 3.5 and 3.6, the particle size (or diameter'd' of the particle), particle size parameter x and other necessary parameters were calculated precisely and the results were presented in table 4.4

Table 4. 4: Calculated summary of different parameters related to scattering of light by oil sample used in the experiment.

Oil sample	$\theta(^0)$	$d(\mu m)$	X	$A(\mu m^2)$	$\rho_s(\mu m^{-3})$	Q_s	Q_{ex}	$\sigma_s(\mu m^2)$
Niger oil	52^0	0.851	5.7881	0.570	0.00495	0.34392	0.34392	0.19562

The particle size of Niger oil was measured and calculated. The scattering angle obtained from the measurement is 0.907 rad and the result of calculation gives d=0.851 μm, and its particle size parameter X=5.7881 with geometrical area 0.570 μm^2 . From this result of calculation it can be concluded that the particle in the oil has its own effect on the scattering of light as well as it affects the quality of the edible oil. In general in this experimental measurement there is an average error of$\pm$0.0001 in particle size determinations. Results of particle size parameter x, tells us that our results in good agreement with Mie scattering theory in which it has the value of x>1, that is the particle size parameter is greater than the wave length of the incident light which is 632.8 nm He-Ne laser for our experiment and as well as the diameter of the scatterer is found in the range of the finest particle category. So, that the finest the particle the highest the scattering coefficient which implies the highest the quality. Therefore, the edible oil used in the experiment as a sample has the highest quality.

Table 4.5 below shows the input parameter from the known values of parameter and the calculated value of parameter and the interactive Mie scattering calculator software give the output parameter of the optical property of the sample Niger oil.

Table 4. 5: Results obtained by using Interactive Mie Scattering Calculator Microsoft ware for input parameters and calculated results

Input parameters	
Sphere(Niger oil) diameter	$0.851\ \mu m\,(calculated)$
Refractive of the medium(hexane)	$1.37(known)$
Real refractive index of sphere	$1.47(known)$
Imaginary refractive index of sphere	$0(known)$
Wavelength in vacuum	$0.6328\mu m\,(known)$
Concentration	$0.00495\frac{sphres}{\mu m^3}(calculated)$
Output parameters(calculated results)	
Wavelength in medium	$0.4619\mu m$
Size parameter x	5.7881
Average cosine of phase function	0.92692
Scattering efficiency	0.34392
Extinction efficiency	0.34392
Back scattering efficiency	0.0052644
Scattering cross section	$0.19562\ \mu m^2$
Extinction cross section	$0.19562\ \mu m^2$
Back scattering cross section	$0.0029943\ \mu m^2$
Scattering coefficient	$0.96831 mm^{-1}$
Total attenuation coefficient	$0.96831 mm^{-1}$

5. CONCLUTION, RECOMMENDATION AND FUTUE PLAN

5.1. Conclusion

Particle size measurement and the determination of particle size distribution are essential to any one dealing with particulate system. Particles have different shapes and are involved in different process. For quality control or system property description purposes, the need to determine the particle size distribution of food becomes apparent, including processing and functionality of many foods. Correct particle size and particle size distribution, particle shape, surface area, and density can lead to food quality. The method for investigation of particle size dependency of quality of edible oil and its optical properties $(\mu_t, \mu_a, \mu_s, \mu_s', g)$, have been developed. The scattering coefficient has direct relation with the particle size as well as the quality; the larger the scattering coefficient is the finest the particle size and the highest the quality.

5.2. Recommendation and future plan

Particle size is one of the most important parameters in materials science and technology as well as many other branches of science and technology, from medicine, pharmacology and biology to ecology, energy technology and the geoscience. The characterization of particulate system is usually made from the analysis of particle size and its distribution. Particle size measurement is most often required a simple quality control technique, a method used to investigate changes in research and design process, and as a requirement in patent or product specification application. As the study indicates the laser light scattering method for investigation oil quality is simple, fast and valid, highly sensitive and more suitable for online monitoring with equipment's mostly available in common laboratories.

The developed methods have wider economic and scientific application for other turbid medium. Light scattering methods is the most preferable for classification of edible oil quality standards. Thus it is recommended that for quality inspection centers and edible oil exporters to use light scattering techniques for their quality standard classifications.

Bibliography

[1]. Central Statistical Agency of Ethiopia (CSA) [2013]. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season); Statistical Bulletin Volume 1: Addis Ababa, Ethiopia.

[2]. Sarwar, M.F.; Sarwar, M.H.; Sarwar, M.; Qadri, N.A.; Moghal, S. [2013]. The role of oilseeds nutrition in human health: A critical review. J. Cereals Oilseeds 4, 97–100

[3]. Gunstone, F. [2011]. Vegetable Oils in Food Technology: Composition, Properties and Uses; John Wiley & Sons: Hoboken, NJ, USA.

[4]. Deosthale, Y.G. [1981] Trace element composition of common oilseeds. J. Am. Oil. Chem. Soc. 58, 988–990.

[5]. Soetan, K.O.; Olaiya, C.O.; Oyewole, O.E. [2010]. The importance of mineral elements for humans, domestic animals, and plants, A review. Afr. J. Food Sci. 4, 200–222.

[6]. Belitz, H.D.; Grosch, W.; Schieberle, P. [2009]. Food Chemistry, 4th revised and extended ed.; Springer: Berlin, Germany.

[7]. Gunstone, F. (2011). Vegetable oils in Food Technology: Composition, Properties and uses; John Wiley and Sons: Hoboken, NJ, USA.

[8]. Deosthale, Y.G [1981), Trace element composition of common oilseeds. J.Am. oil Chem. Soc. 58, 988-990.

[9]. Rossel JB (1991). Vegetable oils and fats, In: Rossel JB, Pritchard JLR (eds)Analysis of oil seeds, fats and fatty foods. Elsevier science, London.

[10]. M.J.Lerma Garcia (2012), characterization and Authentication of olive and other vegetable oils, springer Thesis, DOI: 10.1007/978-3-642-31418-1, Sprenger verlag Berlin Heidel berg.

[11]. Dr. I.P.S. Ahlawat Head, Division of Agronomy Indian Agricultural Research Institute New Delhi – 110 012

[12]. Lideya Tesfaye, Samuel Sahile and Alle Madhusudhan (2015) Microbial Quality and Chemical Characteristics Evaluation of Edible Oil Sold at Gondar Town Markets,Gondar, Ethiopia.

[13]. Tadesse Melaku (2013), Evaluation of Ethiopian Niger seed (Guizotia abyssinica cass) production, seed storage and vergin oil Expression,MSC,Thesis. der Humboldt-Universitat .zu .Berlin.

[14]. Endo. Y.J. Oleo. Sci. [2018], Jan 1; 67(1):1-10. Do i; 10.5650/ jos, ess 17130, Tokyo University of Technology.

[15]. Andrew J.Aubin,Cecilia B. Mazza,Donald A. Trinite, and Patricia McConville(2008) Analysis Of Vegetable Oils By High Performance Liquid Chromatography Using Evaporative Light Scattering Detection And Normal Phase Eluents, Waters Corporation, Milford, MA,U.S.A

[16]. H. G. Fats and Oils, Reinhold Publishing, New York, 1944, pp. 122–123.

[17]. Anonymous (1997), in the Extraction of Oil from Seeds and Nuts.

[18]. Anonymous (2000), in Chronology.

[19]. V. D. (1900). Anderson, Patent 637,354, U.S

[20]. Anonynous (2002).AndersonInternationalCorp.Available:http//www.andersonintl.com/hi.sty.html.

[21]. Endris Taju (2012), laser light scattering for investigation of particle size dependency of quality and flavor of coffee, Masters, Thesis, Addis Ababa University, department of physics.

[22]. Dula Alemu (2015), laser light scattering for investigation of particle size dependency of quality and flavor of coffee, Masters, Thesis, Adama Science and Technology University, department of physics.

[23]. A.Yuz (1996), study of light scattering characteristic of human white blood cells, Pcspie 266-77.

[24]. Hank J (1999), application of Mie theory to large particles, IEEE south east CoN99 Conference.

[25]. Tilahun Abebe (2010), Modeling of scattering and absorption by phanton tissue, Masters, thesis, Addis Ababa University Department of Physics.

[26]. L. Tarsov (1983), Laser Physics and Application, Mir publisher, Moscow.

[27]. Z. Guo and S. Kumar (2001), Fresnel effect in radiation transfer in biological tissue, Applied Optics 40, 3156.

[28]. White H.E. Jenkins, F.A (1957). Fundamentals of optics, 4th ed., McGraw-Hill, Inc, 50 New York, USA,

[29]. Alter C.A Jacques, S.L. and S.A. Prahl (1987), Angular dependence of He-Ne laser light Scattering by human derms, Lasers in the life science 1(4), 3009334.

[30]. Srinivasa G. Narasimhan, Mohit Gupta Acquiring Scattering Properties of Participating Media Carnegie Mellon University

[31]. LV. Wang and HI. Wu (2007), biomedical optics, Bull. Lon-don Math. Soc. ISBN-9780471743040

[32]. Senbeto Kena (2007), Light absorption and scattering by tissue like materials, Masters, thesis, AddisAbaba University, Department of Physics.

[33]. A. J. Cox, Alan J. De Weerd, and Jennifer Linden (2002), An experiment to measure Mie and Rayleigh total scattering cross sections," Am. J. Phys. 70 (6), 620-625.

[34]. Craig F. Bohren and Donald R. Huffman (1983).Absorption and Scattering of Light by SmallParticles Wiley, New York.

[35]. George W. Mulholland, Raymond L. McKenzie, Egon Marx, and Robert A. Fletcher(1985) .RefractiveIndex and Evaporation Rate of Individual Smoke Droplet. Langmuir Vol.I, No.3.

[36]. Gráinne O‟Donnell (2004), Particle Size Determination using Mie Scattering.

[37]. H. C. van de Hulst (1981).Light Scattering by Small Particles, Dover, New York.

[38]. http//www.amazon.co.uk/, Laser beam interaction - materials principle, Application/dp/ 3540594019-60k.

[39]. Mao Ye, Shimin Wang, Yong Lu, Tao Hu, Zhen Zhu, and YiqianXu[1999].Inversion of Particlesize Distribution from Angular Light Scattering Data with Genetic Algorithms,Appl. Opt. 38 , 2677–2685.

[40]. M. Kerker (1969).The scattering of light and other electromagnetic radiation, Academic, New York.

[41]. Zi Ye, Measurements of Particle Size Distribution Based on Mie Scattering Theory and Markov Chain Inversion Algorithm

[42]. Duke Scientific Corporation [1998] published on their website http://www.dukescientific.com

[43]. David W. Hahn, [2009] Light Scattering Theory.

[44]. WWW. Wikipedia, the free encyclopedia, Beer-Lambert law/html

[45]. R. M. Drake and J. E .Gordon [1985]. Mie Scattering, Am. J. Phys.53 (10) 955–962

[46]. M. Kerker [1969].The scattering of light and other electromagnetic radiation. Academic, New York

[47]. Warren Wiscombe [1980], Improved Mie Scattering Algorithms, Appl. Opt. 19 (9), 1505- 631509